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Sediment Resuspension by Ship Traffic in Newark Bay, New Jersey

Doug Clarke, Kevin J. Reine, Chuck Dickerson,
Catherine Alcoba, Jenine Gallo, Bryce Wisemiller,
and Sarah Zappala

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Sediment Resuspension by Ship Traffic in Newark Bay, New Jersey

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Final report

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Abstract

A frequently cited concern for potential detrimental impacts to aquatic organisms associated with dredging projects is sediment resuspension at the dredging site or at an open-water placement site. However, very few attempts have been made to place dredging-induced resuspension into perspective with other natural (e.g., tidal flows, high riverine discharges, storm wind and wave forces) or anthropogenic (e.g., commercial or recreational vessel traffic passage and maneuvering) sources of resuspension. The present study examines suspended sediment plumes created by various types of vessels within Newark Bay, New Jersey. Spatial scales, total suspended solids (TSS) concentration gradients, and dispersion patterns were measured by a combination of acoustic Doppler current profiler (ADCP) surveys and collection of water samples for gravimetric analysis. Plumes varied substantially among vessel type and movement patterns. Often very large plumes, initially extending from the surface to the bottom, were associated with turning maneuvers of deep draft vessels. Plumes rapidly dissipated in the upper portion of the water column, but persisted at depth for relatively long periods. TSS concentrations above 90 mg/l occurred over broad areas following vessel maneuvers. Ambient TSS concentrations ranged from 10 mg/l (surface) to 60 mg/l (just above the bottom). Bottom plumes remained detectable against ambient throughout the time intervals between successive arrivals and departures, persisting for at least 50 minutes where tidal currents could disperse plumes. Residual plumes (maximum 40 mg/l) in the lower 2 m of the water column were detectable at the point of deep draft vessel passage up to 65 minutes.

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Preface

This study was a joint effort between the U.S. Army Engineer Research and Development Center (ERDC); the U.S. Army Engineer District: New York; HDR, Inc.; and Bowhead Information Technology Services, under the Dredging Operations Technical Support (DOTS) Program.

The principal investigators for this study were Dr. Douglas Clarke (formerly of ERDC) and Kevin J. Reine of the Wetlands and Coastal Ecology Branch (CEERD-EEW) of the Ecosystem Evaluation and Engineering Division (CEERD-EE), ERDC, Environmental Laboratory (EL). At the time of publication, Patricia Tuminello was Chief, CEERD-EEW; Mark Farr was Chief, CEERD-EE; Dr. Jack Davis was the Deputy Director of ERDC-EL, and Dr. Beth Fleming was the ERDC-EL Director.

LTC John T. Tucker III was the Acting Commander of ERDC, and Dr. Jeffrey P. Holland was the Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
knots	0.51444444	meters per second
miles (nautical)	1.852	meters
miles per hour	0.44704	meters per second
yards	0.9144	meters
milligrams per liter	0.001	grams per liter

1 Introduction

Many of the environmental concerns that arise in connection with navigation dredging projects are linked to sediment resuspension. The primary assertion of resource agencies is that dredging places a mass of sediment into suspension on spatial and temporal scales sufficient to cause detrimental effects on aquatic organisms or their habitats. While historically a great deal of effort has been made to characterize and quantify sediment resuspension by various dredge types in a wide variety of settings, comparatively little effort has been directed at other sources of resuspension that contribute to the overall sediment resuspension budget in a given waterway, harbor, or estuary. Additionally, few attempts have been made to evaluate other natural (e.g., tidal flows, high riverine discharges, storm wind and wave forces) or anthropogenic sources (e.g., commercial or recreational vessel traffic passage and maneuvering) of resuspension (e.g., Fredette et al. 1988; Gelinas et al. 2013; Houser 2011; Schoellhamer 1996; Stevens 2003; Ruffin 1998; Durrieu de Madron et al. 2005; Ferre et al. 2005; Dellapenna et al. 2006; Lohrer et al. 2006; Maa et al. 2007; Maynard 1998; Parchure et al. 2007) or specifically to place dredging into perspective with other sources (Bohlen et al. 1979; Bohlen 1980; Tramontano and Bohlen 1984; Sosnowski 1984; Pennekamp et al. 1991; Schoellhamer 2002). Sediment resuspension by shallow draft vessels has received attention periodically (Johnson 1976; Liou and Herbich 1976; Barr 1993; Savino et al. 1994; Keldermann et al. 1998; Copeland et al. 2001; Penczak et al. 2002). Anecdotal evidence suggested that the extent of sediment resuspension attributable to this traffic was significant (e.g., see Figure 1). However, resuspension due to deep draft vessel traffic has seldom been considered in tandem with dredging (Erdmann et al. 1994; Munawar et al. 1991; Clarke et al. 2007a,b; Garel et al. 2008; Jones 2011), although the two are integral aspects of navigation infrastructure operation and maintenance. Accurate impact assessments of dredging should involve determination of the increment of sediment mass inserted into the water column by dredging as compared to these other sources. Characterization of the spatial scales and temporal dynamics of dredging-induced resuspension severely constrains

such assessments. Whether or not dredging represents a meaningful increment above ambient¹ conditions in terms of spatial extent, dose (concentration integrated through time) or frequency of exposure can only be determined when the components of the sediment resuspension budget within a water are known.

Figure 1. Aerial photograph (12/28/2001) of Port Elizabeth, New Jersey. Note the prominent plume behind the container ship that is entering the Elizabeth Channel stern first (at the upper right) and the container ship moving north along the eastern berthing areas (left side). An operating dredge is also visible at the entrance to the Elizabeth Channel. (Image courtesy of the Port Authority of New York and New Jersey).



Given the continuing trend for construction of larger deep draft vessels and the need for harbor modifications to accommodate them, knowledge gaps related to spatial and temporal scales of vessel-induced sediment resuspension are readily apparent.

Newark Bay (NB) experiences a high frequency of deep draft vessel traffic on a daily basis. The present study was designed to determine the scales and dynamics of ship-induced sediment resuspension in Newark Bay, New Jersey. During the course of navigation dredging monitoring activities, opportunities arose to examine the resuspension characteristics of vessels

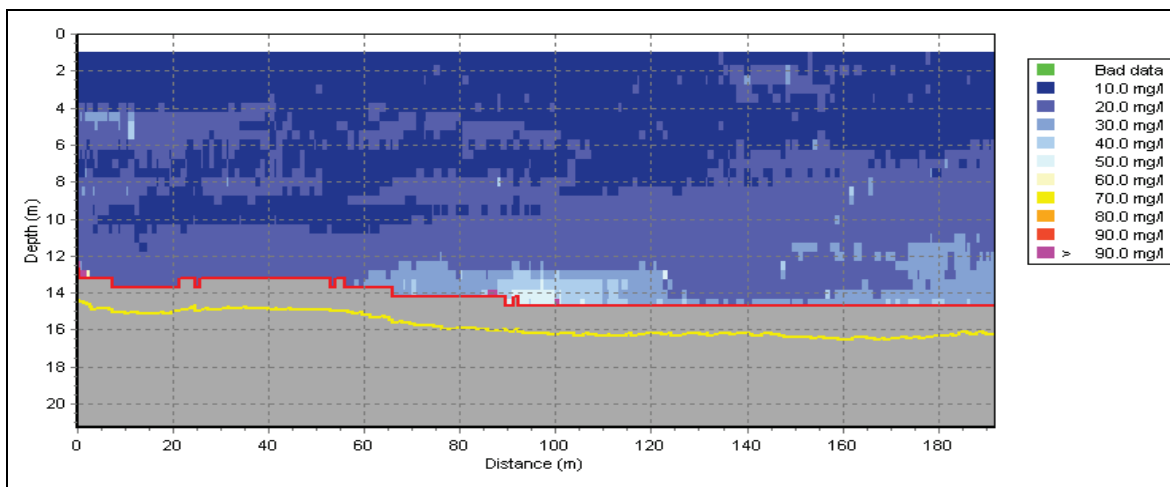
¹ As treated herein, “ambient” refers to natural conditions as distinguished from anthropogenic effects. However, awareness is necessary of the fact that in a system such as Newark Bay subtle influences of anthropogenic activities are always present.

arriving and departing from the Port of Elizabeth and the Port of Newark. Since 2004, the New York & New Jersey Harbor Deepening Project, under construction by the U.S. Army Corps of Engineers, New York District, in partnership with the Port Authority of New York and New Jersey, has conducted a multi-year water quality monitoring program to collect, assess, and document the resuspension associated with the project's ongoing construction. As part of this monitoring program, to provide quantitative comparison and to utilize the ample opportunities provided during times of dredge inactivity, a water quality monitoring study was designed and executed to also monitor suspended sediment plumes associated with nearby ship traffic. This collaborative effort between the U.S. Army Corps of Engineers (USACE) - New York District (NYD), with contractual support by HDR Engineering, the USACE Engineer Research and Development Center (ERDC), and the Port Authority of New York and New Jersey (PANYNJ), resulted in the design and execution of dedicated field efforts to monitor suspended sediment plumes associated with ship traffic. Ship traffic data were collected on three separate occasions in July 2006, January 2007, and November 2009.

2 Methods

Plumes were surveyed with an acoustic Doppler current profiler (ADCP) using methods consistent with those described in detail in Clarke et al. (2007b) for monitoring of dredge plumes in the Arthur Kill Waterway. Since several of the surveys described herein were completed opportunistically during periods of dredge inactivity, dedicated surveys of ambient conditions were not conducted in tandem with every ship plume survey. However, ambient data were collected in the same sections of the navigation channels during all three sets of surveys. Frequently, transects were completed immediately prior to the passage of a deep draft vessel. On occasion, a “broad area” survey was conducted, consisting of multiple zig-zag transects across the open expanse of mid-bay waters and long linear transects from the bay water to the inner terminus of each secondary channel. It should be recognized, however, that true ambient conditions, defined as naturally occurring, undisturbed conditions, are probably never present in a busy port complex exemplified by Newark Bay. Additional data describing ambient conditions were derived from surveys of current patterns of the Port Elizabeth Harbor complex. A typical ambient transect is exemplified in Figure 2, which was located in the same location as the first series of ship resuspension surveys. On this transect, the upper half of the water column had total suspended solids (TSS) concentrations in the 10 to 30 mg/l range. Concentrations were higher in the lower portion of the water column, with a thin layer of up to 60 mg/l just above the bottom. These near-bottom conditions may represent a residual plume from an earlier ship passage. Note that the “bad data” category in all figure legends refers to segments of ADCP data influenced by beam side lobe or bottom interferences in the acoustic signals. Likewise, in all ADCP vertical profile figures, the yellow line represents the actual sediment-water interface as indicated by the echo return, whereas the red line indicates the lowest depth of accurate acoustic returns for estimating TSS concentration.

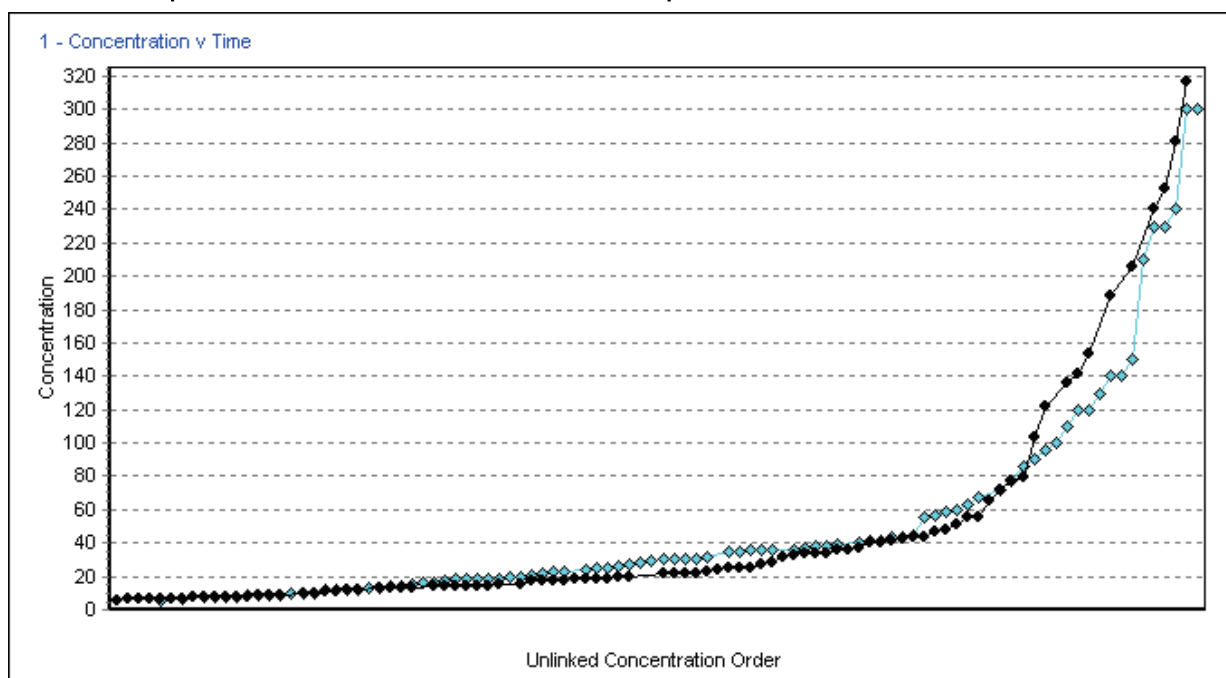
Figure 2. Ambient TSS concentrations across a transect on 6 July 2006 during a middle phase of a flooding tide. This transect location corresponds with that of ensuing ship passage surveys.



Water sampling in the ship plumes was not conducted, so a dedicated data set for calibration of the ADCP for acoustic backscatter conversion to TSS concentration was not obtained. However, a calibration data set based upon water samples collected in the Port Elizabeth channels during mechanical dredging was available and applied to the ADCP data. The team converted acoustic backscatter data to estimates of TSS concentration by application of a calibration procedure described by Land and Bray (2000). The degree of confidence that can be placed in the estimates of concentration is proportional to the strength of the calibration data set. The quality of the calibration is, in turn, dependent on the collection of adequate water samples to represent sediments in suspension at all depths in the water column and across the entire gradient of concentrations occurring in ambient as well as plume waters. In this study, 89 water samples — ranging in TSS concentration from 5.6 to 300 mg/l — produced an excellent calibration, although the overall number of samples at the upper end of the concentration gradient was limited. In Figure 3, the entire population of gravimetric measurements derived from water samples and acoustic estimates derived from ADCP backscatter data are arranged in rank order. A relatively strong correspondence exists between the two measures throughout the sampled range, although acoustic estimates tend to slightly overestimate concentration in the high range. Collection of high concentration samples proved to be difficult because of the very small down-current distances from the source at which high concentrations could be found. Safety factors prevented the survey vessel from maneuvering sufficiently close to the dredge to consistently obtain such samples. Thus, figures of vertical profiles through ship plumes reported herein should be

viewed as estimates of TSS concentrations depicting general concentration gradient structure and not precise measurements. As in the case of dredge plumes, air entrainment in the vessel prop-wash is a significant source of acoustic energy reflection, so that acoustic signatures directly behind a vessel's passage can be contaminated with air. As time elapses, air bubbles rise and dissipate considerably faster than fine suspended sediment particles settle so truer estimates of TSS concentration can then be derived. These caveats should be considered in interpretation of the results of the present study.

Figure 3. Comparison of gravimetric and acoustic estimates of TSS concentration for an entire population of 89 water samples in rank order. Gravimetric results are represented in blue and acoustic estimates in black.



The task of capturing the spatial and temporal scales of plumes created by moving ships posed several challenges. Movement of the source of resuspension created large but diffuse plumes. Limitations on spatial coverage imposed by maximum speeds at which ADCP data can be collected led to a strategy in which a single transect which traversed the entire width of the plume was resurveyed repeatedly. This approach enabled collection of time series data depicting the decay of the plume at the selected location. After sufficient time had elapsed following passage of the vessel to allow bubbles within the vessel's wake to dissipate, estimates could be derived of TSS concentration structure within the plume. This approach, therefore, did not assess the overall dimensions of the plume. In order to characterize the overall plume dimensions, a zig-zag transect design was employed,

essentially following the water mass encompassing the plume as it was carried by tidal flows in an ebbing or flooding direction.

To collect time series data of optical turbidity at selected fixed locations, multiple Campbell Scientific OB-3A optical backscatter sensors (OBS) were deployed on taut-line buoys at the start of each survey day and recovered at the conclusion of each day. Surveys were constrained to daylight hours for safety reasons.

3 Results

Field Surveys

Specifications and dimensions of deep-draft vessels that were encountered during the three separate field efforts are given in Table 1. Note that beam width of the ships is not listed due to the fact that all ships had an equivalent beam width of 32m. This reflects the existing width constraints imposed on vessels that transit the Panama Canal.

Table 1. Dimensions of deep-draft vessels involved in sediment resuspension surveys in Newark Bay, New Jersey. Vessel specifications were derived from MarineTraffic.com. All vessels had a beam width of 32m.

Vessel	Date	Length (m)	Tons (gross)	Draft (m)	Type	Direction
YM North	Jul 2006	275	46,697	11.3	Container	Inbound
ARC Freedom	Jul 2006	190	49,821	9.4	Car Carrier	Outbound
CMA CGM Hudson	Jul 2006	210	32,671	10.5	Container	Inbound
CSCL Melbourne	Jul 2006	260	39,941	11.9	Container	Inbound
Zim New York	Jan 2007	294	53,453	11.6	Container	Inbound
APL Turquoise	Jan 2007	294	52,086	11.1	Container	Inbound
Atlantic Concert	Jan 2007	291	57,255	9.2	RORO ¹ - Container	Inbound
APL Egypt	Jan 2007	294	54,415	10.5	Container	Outbound
Cosco Luobahe	Nov 2009	243	36,772	9.5	Container	Inbound
MSC Fabienne	Nov 2009	293	54,774	13.5	Container	Outbound
Mandarin Sky	Nov 2009	190	32,957	11.8	Bulk Carrier	Inbound
Dubai Express	Nov 2009	260	39,941	10.8	Container	Outbound
MSC Noa	Nov 2009	240	35,953	9.7	Container	Inbound

¹RORO – Roll On Roll Off

July 2006 Ship Traffic Survey Series

The initial survey of ship-induced resuspension of bottom sediments was conducted on 9 July 2006 during slack water conditions following an ebbing tide. At the time of this survey, the channels had been dredged in 2002-2004 to 14.3 m depth at mean low water. The Yang Ming Line container ship *YM North* progressed northward along the Newark Bay Middle Reach Channel and arrived at the outer junction with the Port Elizabeth Channel at approximately 1300 hr. Assisted by tugs, the vessel rotated to enter port stern first. The *YM North* then continued stern first

into the Elizabeth Channel and docked. During the rotation maneuver, a prominent surface plume of increased turbidity was generated (Figures 4 and 5).

Figure 4. Surface turbidity plume created by maneuvering the container ship *YM North*.



Figure 5. Surface turbidity plume created by maneuvering the container ship *YM North*.



A repetitive ADCP transect was established across the area in which the ship had turned (Figure 6), extending from the northeast corner of the Port Elizabeth Marine Terminal (PEMT) to the red channel marker buoy “R 14.” Immediately after passage of the ship, nine survey lines were completed between 1309 and 1404 hr. The first transect (Figure 7) passed through the wake directly behind the *YM North*. A significant amount of air was entrained in the water column by the ship’s propeller as indicated by the intense pink areas in the figure. Although air contamination prevents TSS estimation on this transect, bottom disturbance and turbulence throughout the water column is clearly evident. A second transect (Figure 8) was conducted approximately 6 min after completion of the first transect. Most of the entrained air had dissipated upward and is seen as a distinct surface feature. A clear acoustic signature of bottom resuspension was present with concentrations greater than 90 mg/l in the lower half of the water column. A third transect (Figure 9) was completed approximately 19 min after the first transect. A general settling and spreading of the plume had occurred with concentrations as high as 70 to 80 mg/l near the bottom. A fourth transect (Figure 10) was conducted approximately 24 min after the first transect, with a TSS pattern similar to that observed on the previous transect. TSS concentrations near the bottom were as high as 90 mg/l. A fifth transect (Figure 11) was conducted approximately 29 min after the first transect and indicated further settling of the plume. Concentrations near the bottom were as high as 70 mg/l.

At approximately 1330 hr the car carrier *ARC Freedom* exited Port Newark and crossed the repetitive transect at approximately 1342 hr (Figures 12 and 13). Markings on the hull of the *ARC Freedom* indicated that it had a draft of approximately 9.2 m. Simultaneously, a tug pushing a loaded dredge barge exited Port Elizabeth and transited the area (Figure 14). Both vessels were heading southward down the Newark Bay Middle Reach Channel.

The sixth transect (Figure 15) in this series was conducted approximately 33 min after the first transect, crossing astern of the *ARC Freedom* as closely as possible. Air is clearly present in the wake signatures of both the *ARC Freedom* on the right and the tug and barge on the left. The wake signatures from the tug and barge indicated disturbance to a depth of approximately 6 m, whereas the car carrier’s wake signature extended to a depth of approximately 12 m. Neither vessel appeared to induce appreciable resuspension of the bottom. The plume created earlier by the *YM North* remained easily detectable, with TSS concentrations near the bottom still as high as 70 to 80 mg/l.

Figure 6. Repetitive transect location (denoted in red).

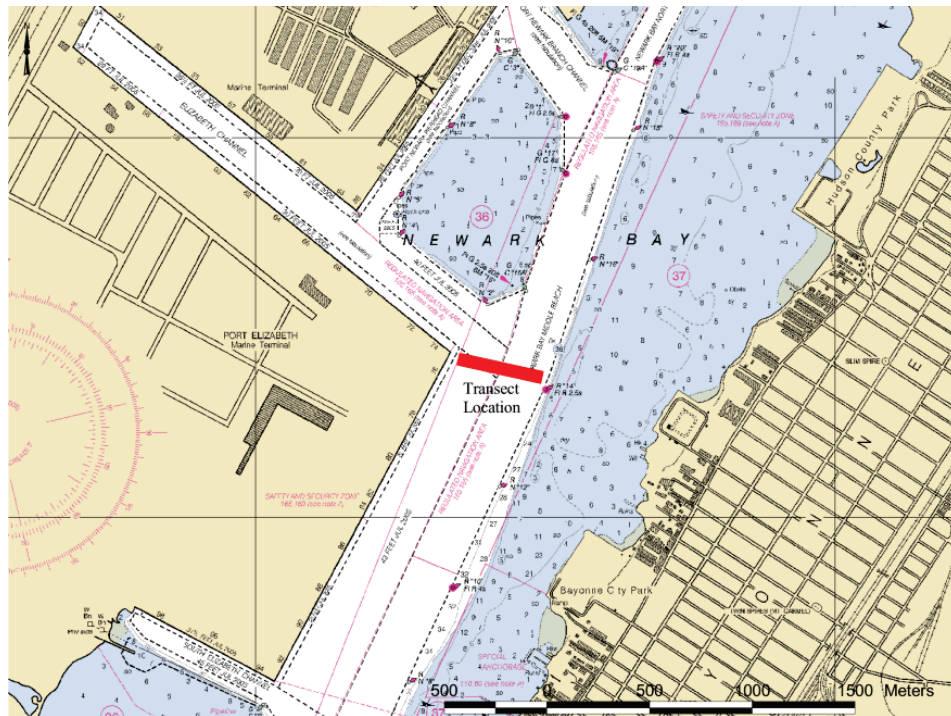


Figure 7. First transect directly behind YM North (Time 0).

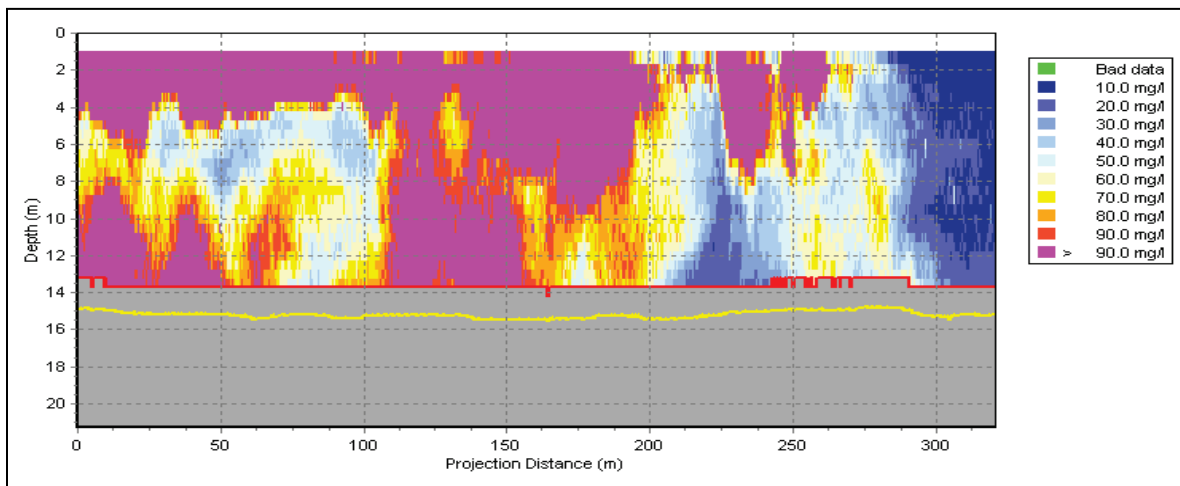


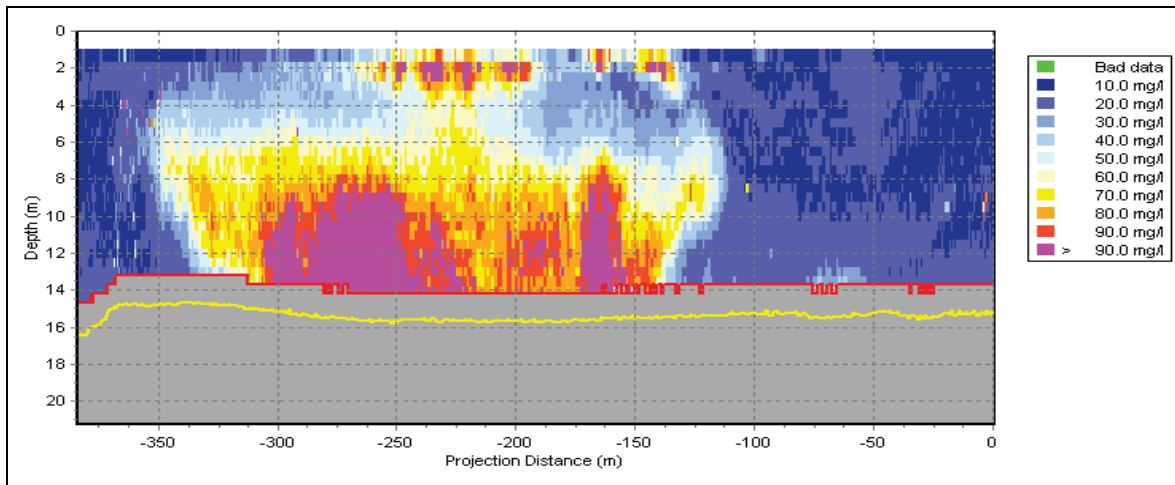
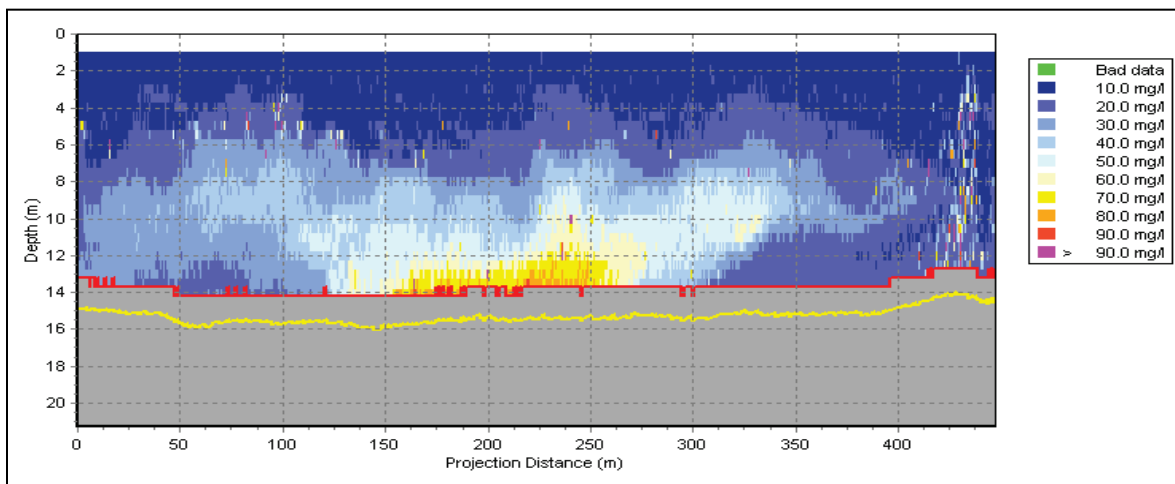
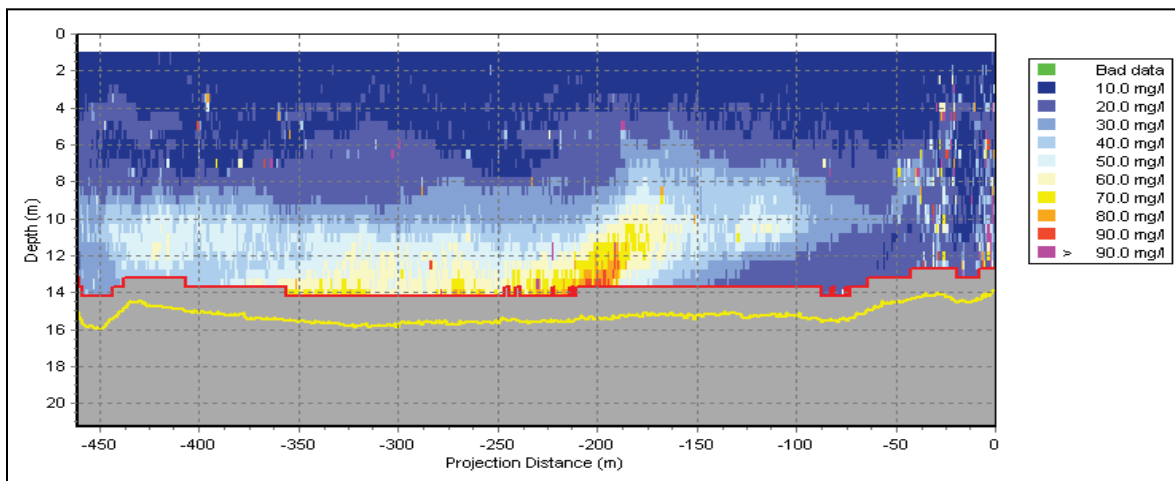
Figure 8. Second transect behind *YM North* 6 min after first transect.Figure 9. Third transect behind *YM North* 19 min after first transect.Figure 10. Fourth transect behind *YM North* 24 min after first transect.

Figure 11. Fifth transect behind *YM North 29* min after first transect.

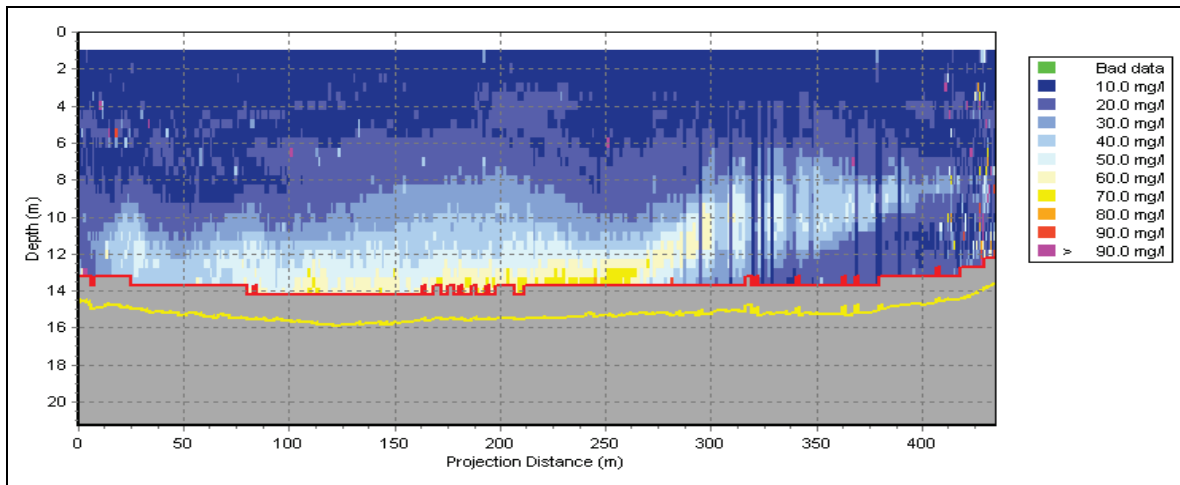


Figure 12. Car carrier *ARC Freedom* approaching repetitive transect location.



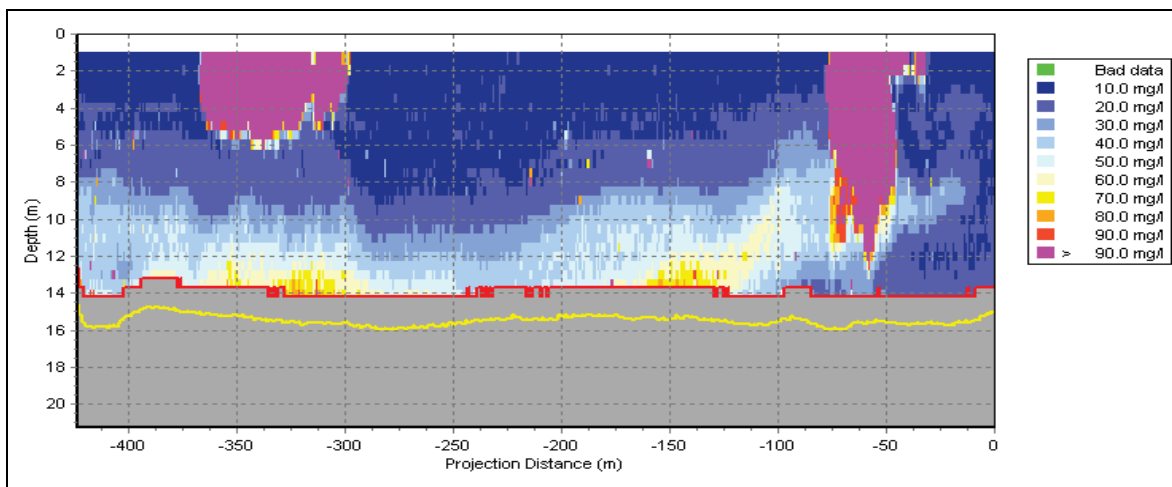
Figure 13. Car carrier ARC *Freedom* crossing repetitive transect.



Figure 14. Tug and loaded scow crossing repetitive transect.



Figure 15. Sixth transect behind *YM North* 33 min after first transect; the sixth transect shows ship wake signatures of a tug and barge (left) and the car carrier *ARC Freedom* (right).



A seventh transect (Figure 16) was conducted approximately 40 minutes after the first transect. The wake signature from the tug and barge persisted to a depth of approximately 6 m; however, the wake signature from the *ARC Freedom* had dissipated. Settling of the original plume continued with a few isolated patches of TSS concentrations as high as 70 mg/l. Concentrations near the bottom were now approximately 50 to 60 mg/l. The eighth transect (Figure 17) was conducted approximately 45 min after the first transect. Vestiges of the *YM North* plume remained near the bottom at TSS concentrations less than 60 mg/l.

Figure 16. Seventh transect behind *YM North* 40 min after first transect, with the wake signature of the tug and scow still visible on the left, while the wake signature from the car carrier *ARC Freedom* has dissipated.

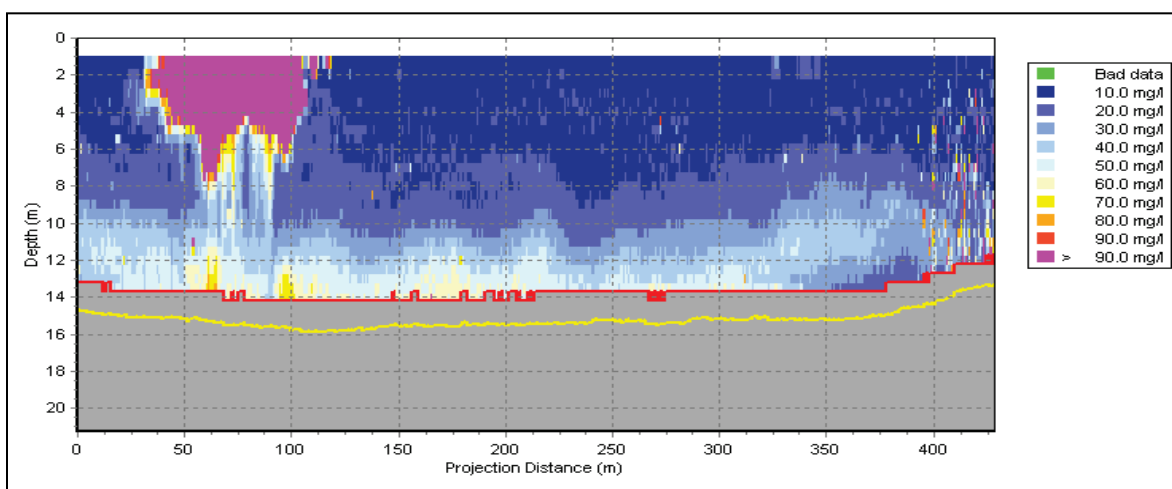
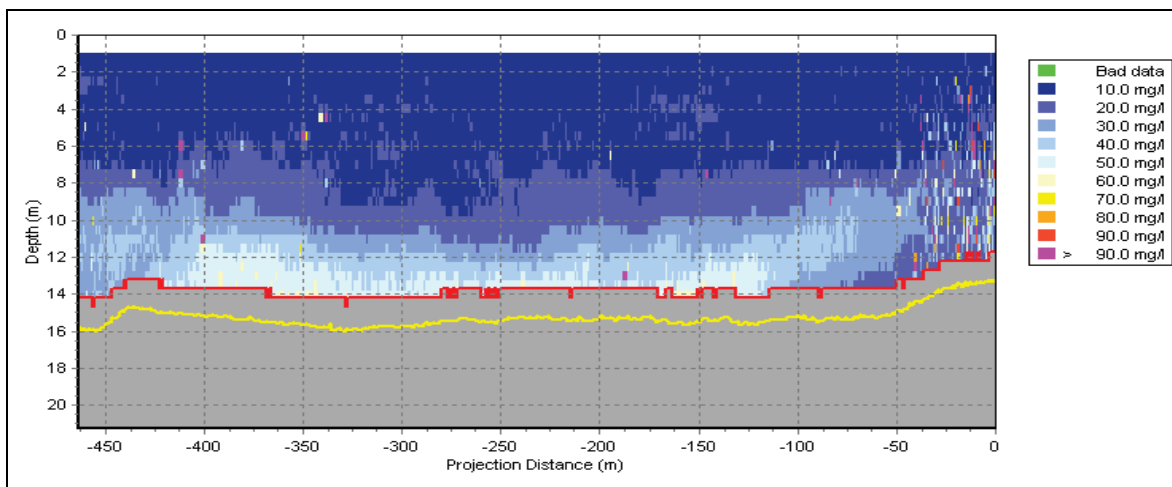


Figure 17. Eighth transect occupied behind the container vessel *YM North* 45 min after first transect, both wake signatures now dissipated.

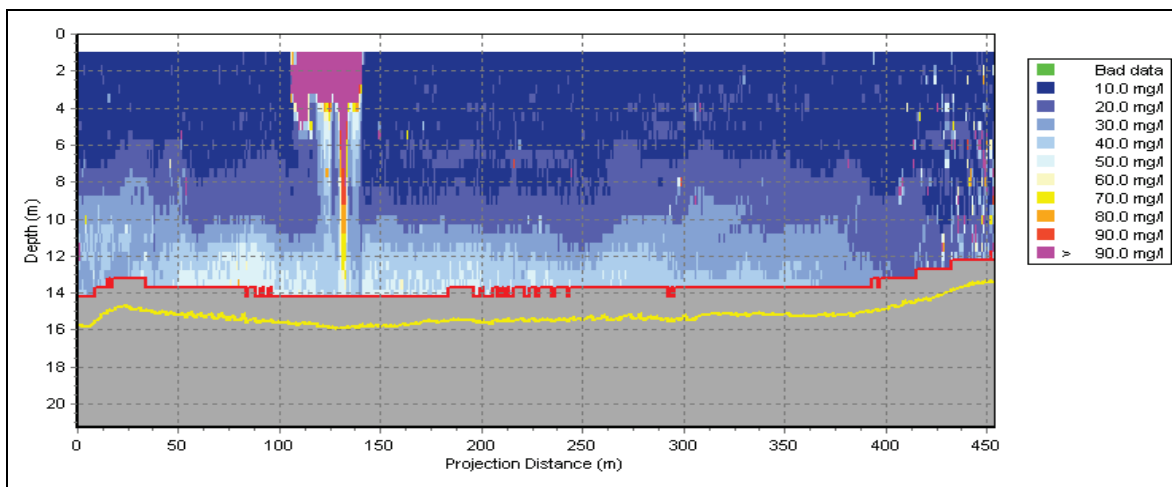


Just prior to the start of the ninth and final transect of this repetitive line survey, the tug *Iona McAlister* (Figure 18), which had been assisting in docking operations of the *YM North*, departed Port Elizabeth and crossed the repetitive transect line. The ninth transect (Figure 19) was conducted approximately 50 min after the first transect behind the *YM North* and shows the wake signature of the tug *Iona McAlister*. The resuspension plume from the *YM North* was still visible, with concentrations less than 50 mg/l near the bottom. At this point in time, the ADCP survey series was terminated.

Figure 18. Tug *Iona McAlister* crossing repetitive transect.



Figure 19. Ninth transect behind *YM North* 50 min after first transect; the ninth transect shows wake signature of entrained air from tug boat *Iona McAlister*.



A second series of repetitive ADCP transects was conducted on 10 July 2006 during slack water conditions following an ebbing tide between 1358 and 1517 hr. This survey consisted of 10 transects along the same path as shown in Figure 3 for the previous series. Prior to the start of the survey, the container ship *Hudson* (Figure 20) entered Port Elizabeth. An exact time that the *Hudson* transited the survey line was not available, but was estimated to be less than 30 min prior to the start of the survey.

Figure 20. Container ship CMA CGM *Hudson* docked prior to second survey.



A prepassage transect (Figure 21) was conducted just prior to the arrival of the container ship CSCL *Melbourne* (Figure 22). Note that due to the presence of a residual plume from the recent passage of the *Hudson* this transect does not depict true “ambient” conditions. Unlike the maneuvering of the *YM North*, which used the outer portion of the Port Elizabeth Channel to turn and enter Port Elizabeth stern first, the *Melbourne* simply turned directly into the Port Elizabeth Channel and proceeded to the dock. The *Melbourne* did create a prominent surface turbidity plume (Figure 23).

Figure 21. Residual plume from container ship CMA CGM *Hudson*.

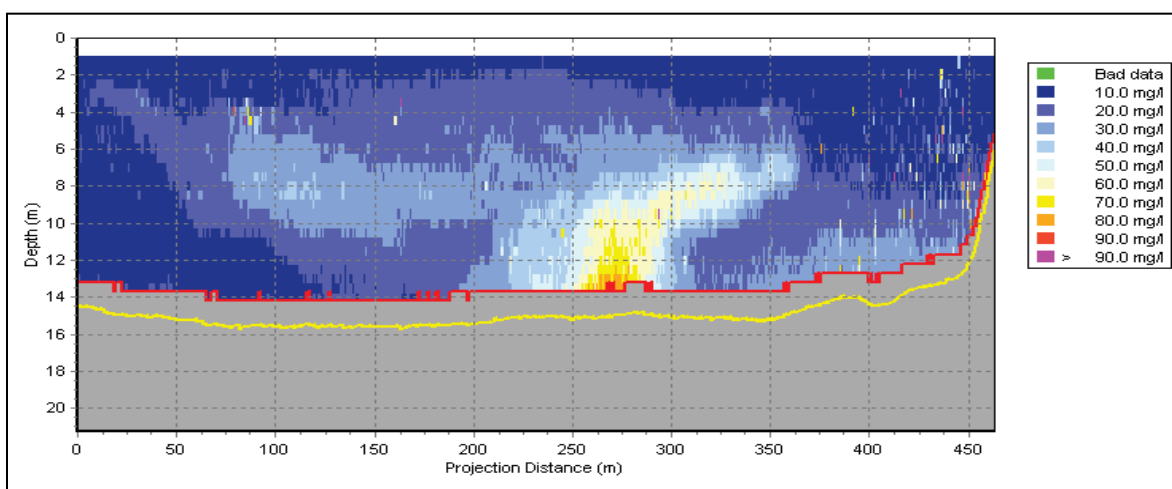


Figure 22. Container ship CSCL *Melbourne* in the Newark Bay Channel.



Figure 23. Surface turbidity created by the container ship CSCL *Melbourne*.



The first transect (Figure 24) of this series passed immediately behind the *Melbourne*. The wake signature from the *Melbourne* (on the left side of the profile) indicated disturbance of the water column from the surface to the bottom. The acoustic signature of the residual plume from the *Hudson* was also still distinct on the right of the figure. A second transect (Figure 25) was run approximately 4 min after the first transect and detected significant disturbance of the bottom (on the left side of the profile), while the residual plume from the *Hudson* remained intact (on the right). A third transect (Figure 26) was completed approximately 9 min after the first transect, revealing TSS concentrations as high as 90 mg/l near the bottom associated with passage of the *Melbourne*. The two separate plumes from the *Hudson* and the *Melbourne* began to merge into a single diffuse plume at this point. A fourth transect (Figure 27) was run approximately 13 min after the first transect. The two plumes were now completely merged into a single plume. TSS concentrations remaining attributable to the *Melbourne* ranged as high as 70 mg/l in one isolated area near the bottom. The fifth transect (Figure 28) was occupied approximately 18 min after the first transect, detecting continued dissipation of the overall plume. TSS concentrations attained a maximum of 50 mg/l or less. A sixth transect (Figure 29), conducted approximately 23 min after the first transect, showed further decay and settlement of the plume, with TSS concentrations generally 40 mg/l or less with a few isolated areas of about 50 mg/l. A seventh transect (Figure 30), conducted approximately 26 min after the first transect, showed little change from the previous transect.

Figure 24. First transect directly behind the *Melbourne* (Time 0). The wake signature of the *Melbourne* is clearly visible on the left, extending from the water surface to the bottom. The residual plume from the *Hudson* is still visible on the right.

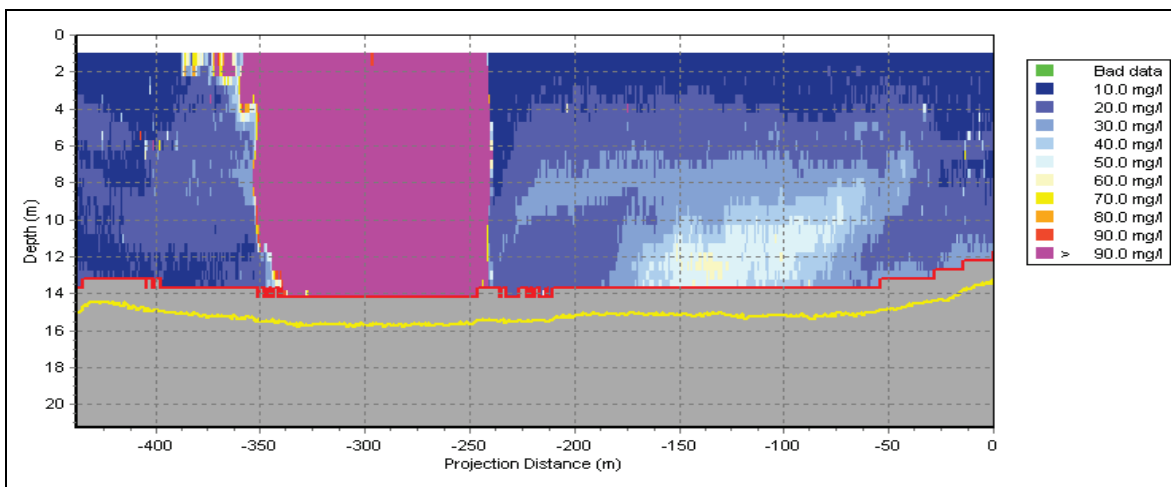


Figure 25. Second transect behind the *Melbourne*, 4 min after first transect.

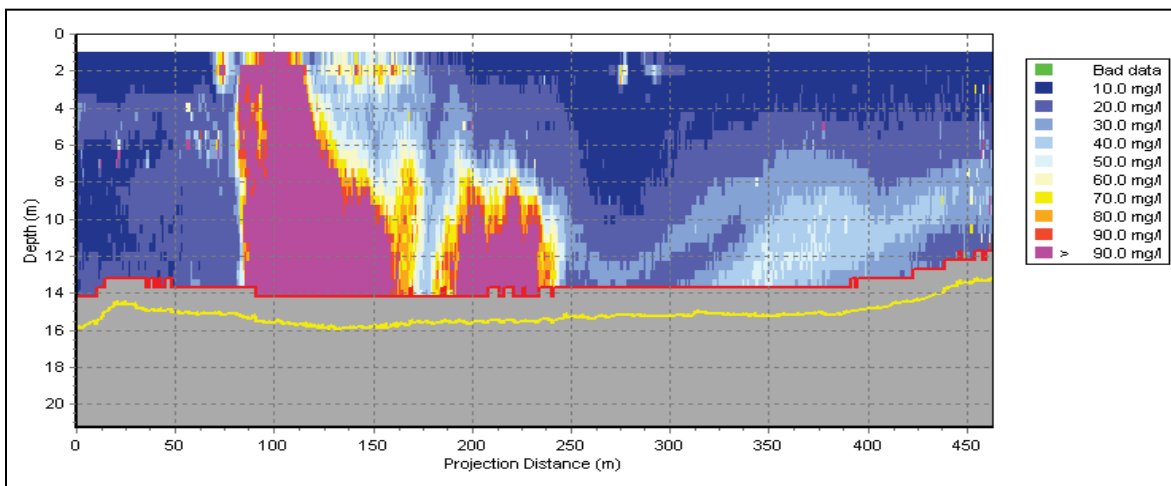


Figure 26. Third transect behind the *Melbourne*, 9 min after first transect.

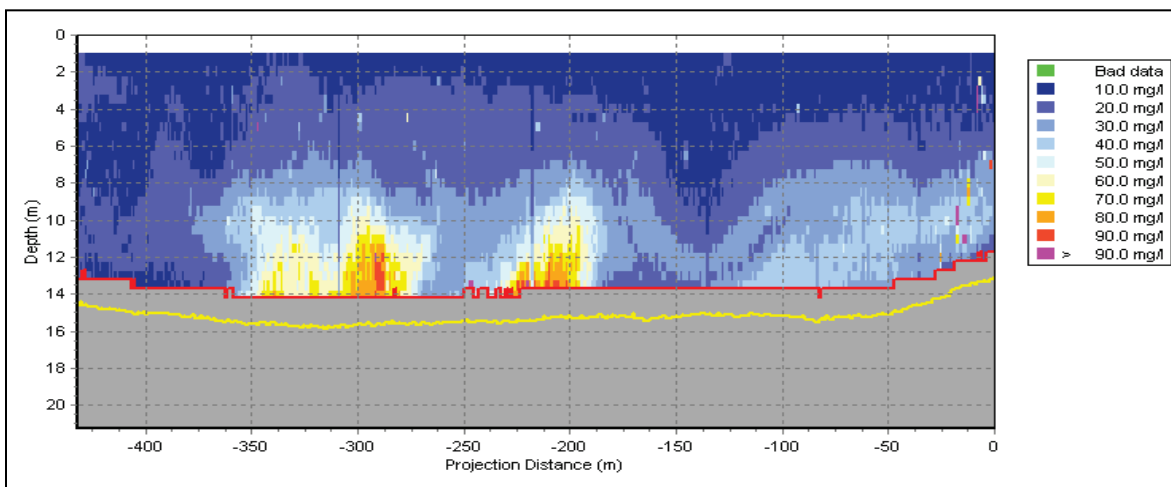


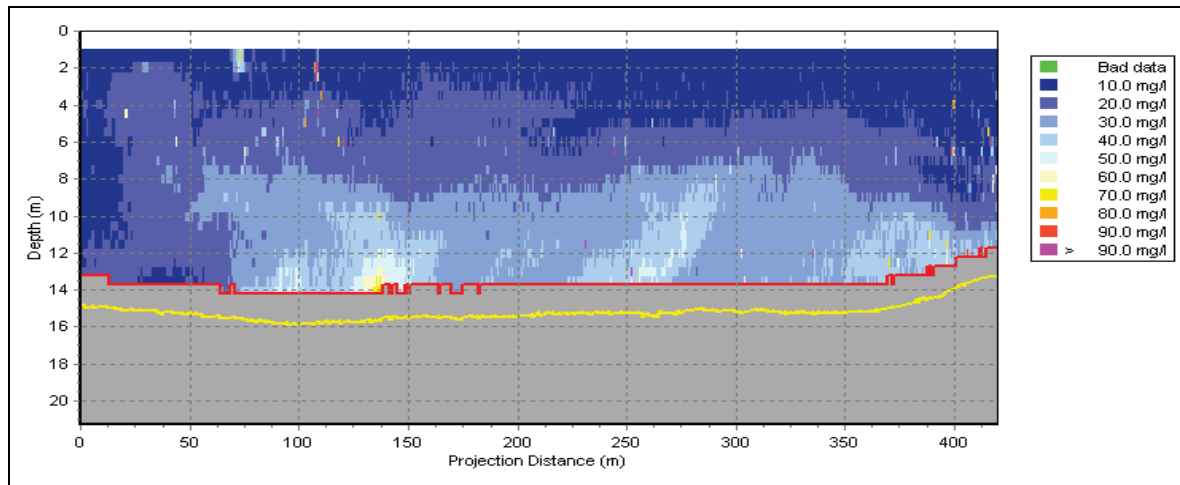
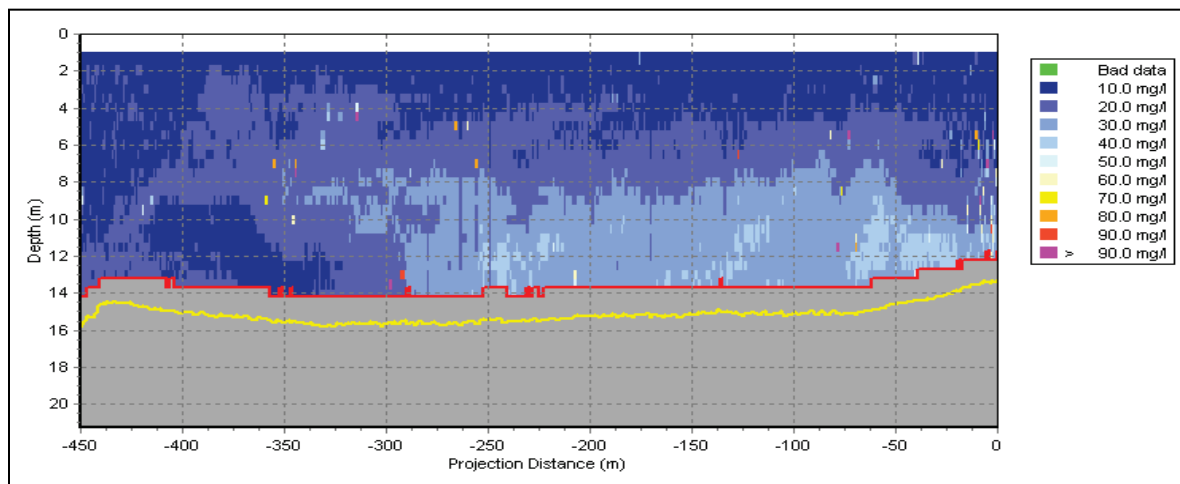
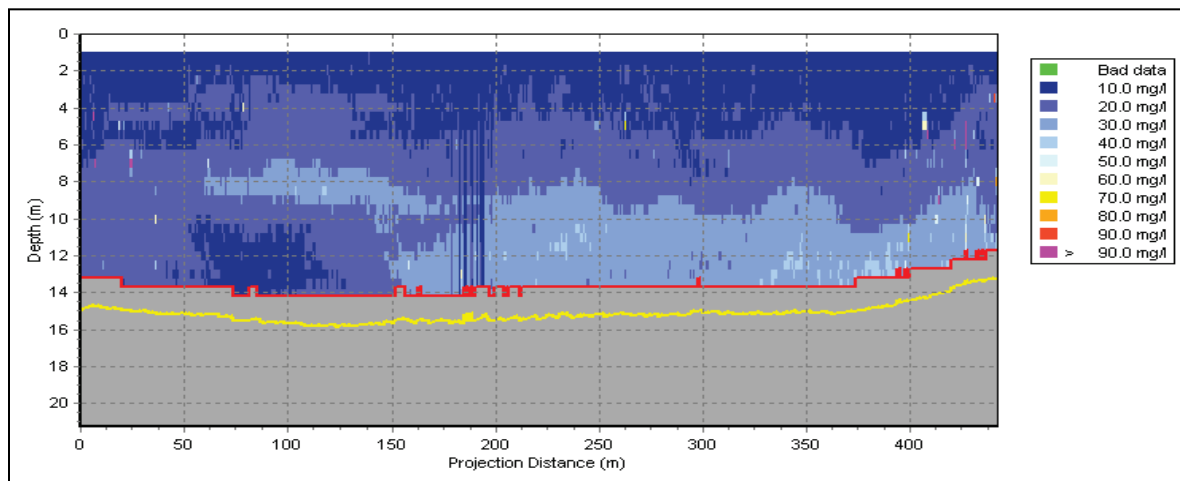
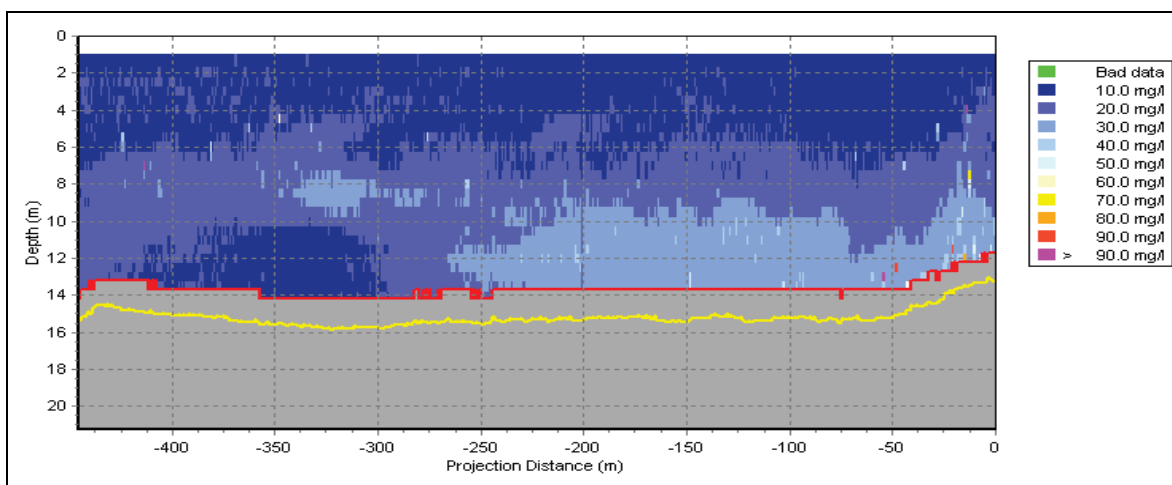
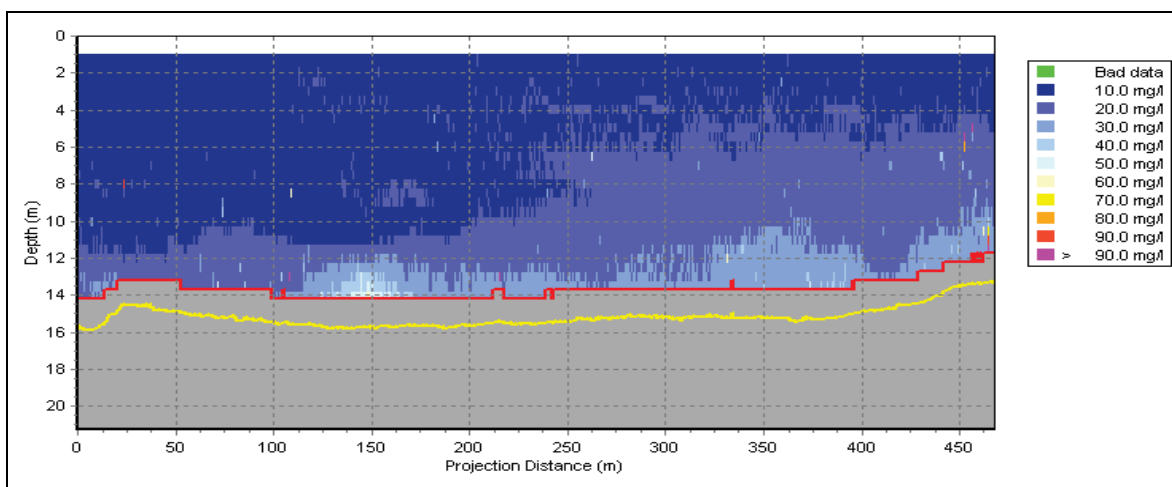
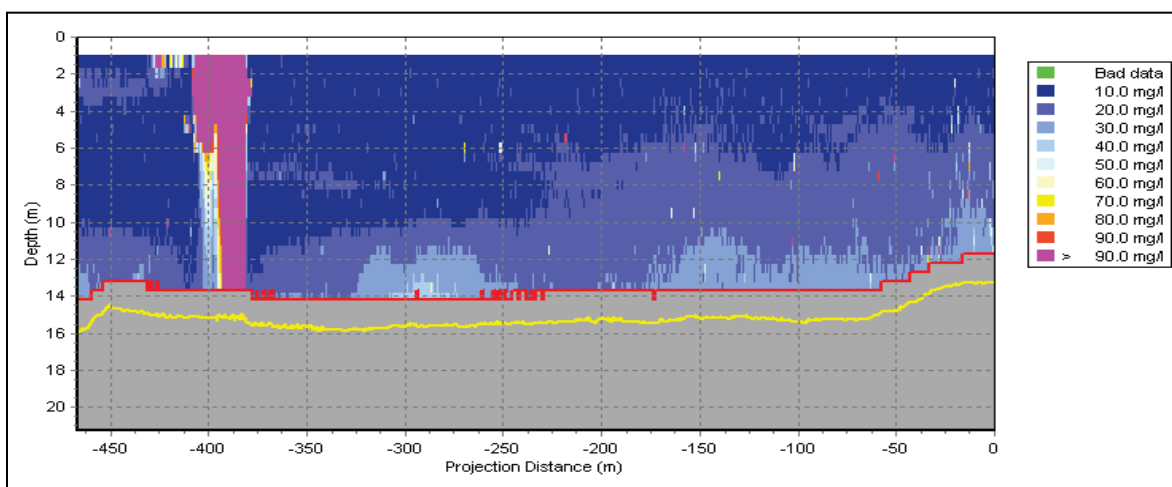
Figure 27. Fourth transect behind the *Melbourne*, 13 min after first transect.Figure 28. Fifth transect behind the *Melbourne*, 18 min after first transect.Figure 29. Sixth transect behind the *Melbourne*, 23 min after first transect.

Figure 30. Seventh transect behind the *Melbourne*, 26 min after first transect.

At 1436 hr the survey was temporarily suspended while the survey vessel went into Port Elizabeth to obtain information about the draft and registry of the container ships *Hudson* and *Melbourne*. The Hudson was observed to draft 10 m at the bow and 10.5 m at the stern. The Melbourne was observed to draft 12 m at the bow and 12.5 m mid-ship.

An eighth transect (Figure 31) was re-established approximately 58 min after the first transect. Substantial settling and dissipation of the plume had occurred in the intervening time period. The residual plume had almost completely settled to within 2 m of the bottom, with concentrations almost entirely less than 40 mg/l. The ninth and final transect (Figure 32) was completed approximately 1 hr and 5 min after the first transect. Just prior to the start of the ninth transect a large tug exited Port Elizabeth and transited the survey location, resulting in the wake signature observed on the left side of the profile. Similar to the previous transect's profile, the plume has now settled to just off the bottom and decayed considerably in concentration. At this point in time the survey series was terminated. Notably, despite current lows, the residual plume along the same transect persisted for over 1 hr following ship passage.

Figure 31. Eighth transect behind the *Melbourne*, 58 min after first transect.Figure 32. Ninth transect behind the *Melbourne*, 1 hr and 5 min after first transect.

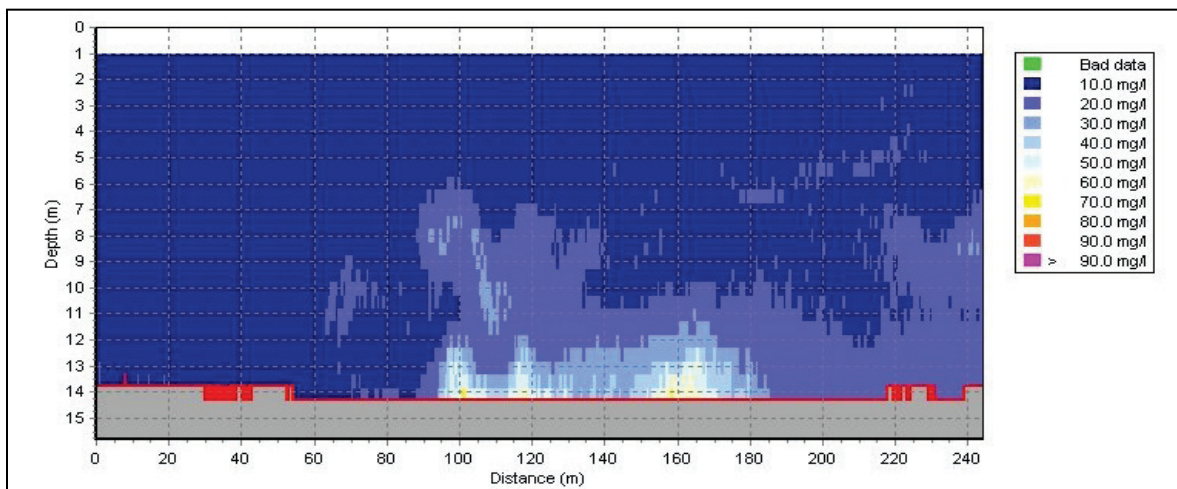
January 2007 Ship Traffic Survey Series

On 22 January, the container ship *Zim New York* (Figure 33) entered Newark Bay at approximately 1215 hr. As the ship progressed northward, an ebbing tide carried the plume southward. The initial set of ADCP transects crossed the plume to the stern of the ship, followed by an additional seven transects in a zig-zag pattern northward to the confluence with the Elizabeth Channel (Figures 33-40). This set of transects captured the extent of the plume generated by turning of the ship to face southward prior to docking at Berths 76/78, which lie at the outer bulkhead at the entrance to the Elizabeth Channel (Figure 41). Of note is the fact that the container ship *Zim Shenzhen* had departed the port just prior to the arrival of the *Zim New York*. Therefore, some residual plume from the *Zim Shenzhen* was probably present during the survey.

Figure 33. The container ship *Zim New York* arriving at Port Elizabeth in Newark Bay.



Figure 34. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, perpendicular to Berth 82 of the PEMT¹.



¹ Note that in Figures 33 through 42 the Port Elizabeth Marine Terminal is abbreviated PEMT.

Figure 35. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*, beginning at Berth 82 of the PEMT.

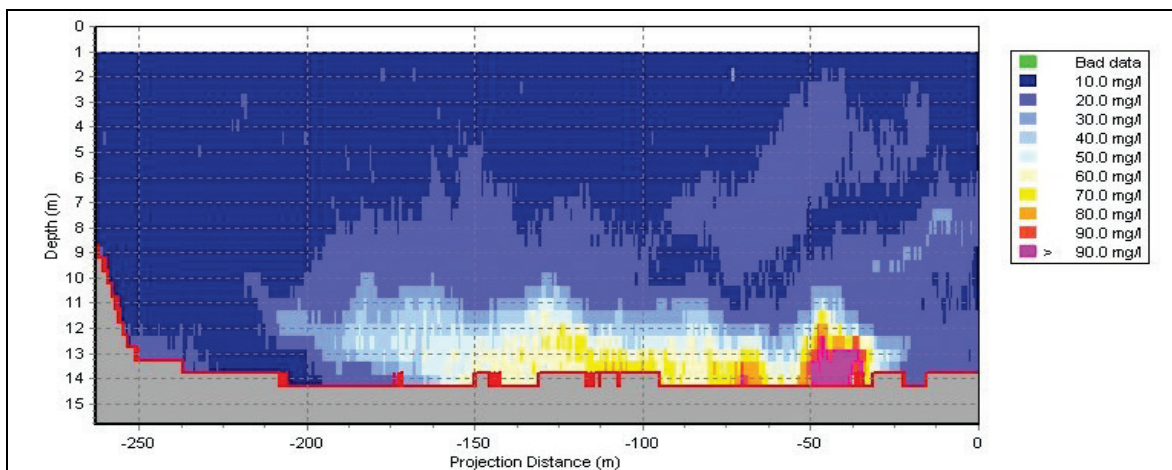


Figure 36. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 80 of the PEMT.

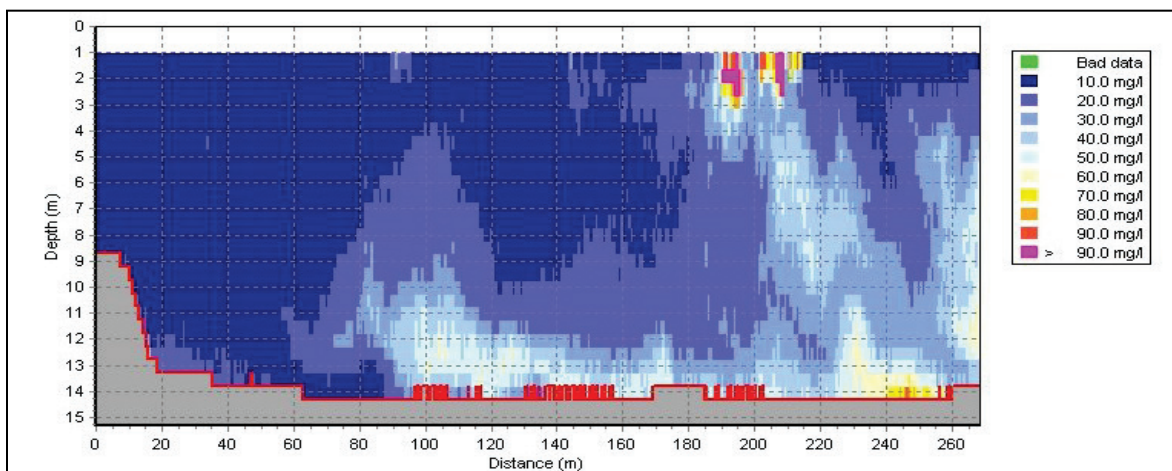


Figure 37. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 80 of the PEMT.

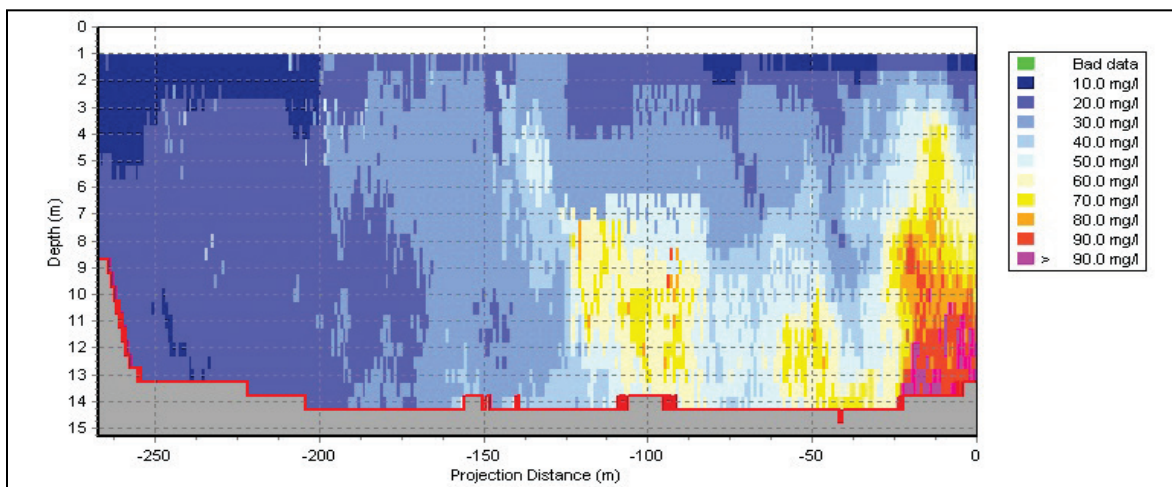


Figure 38. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 80 of the PEMT.

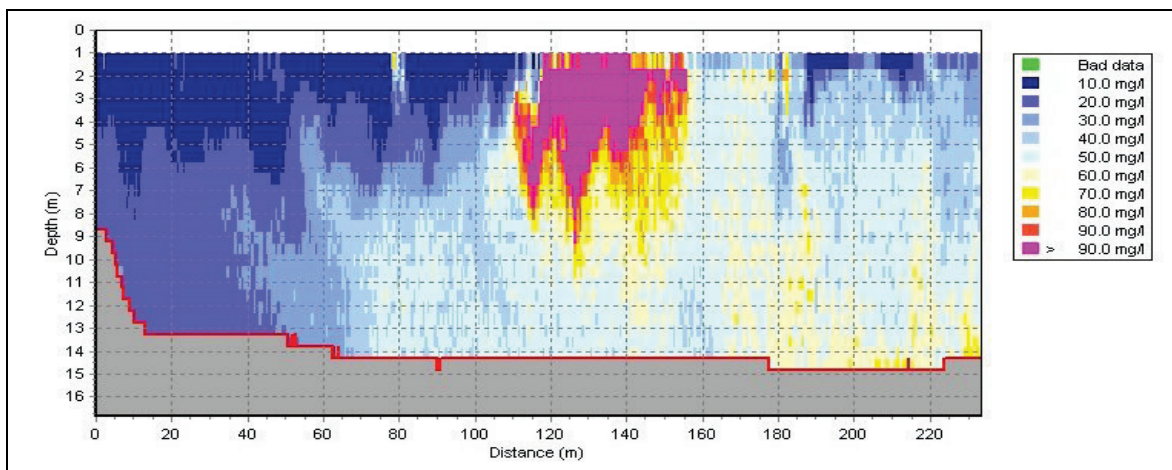


Figure 39. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 80 of the PEMT.

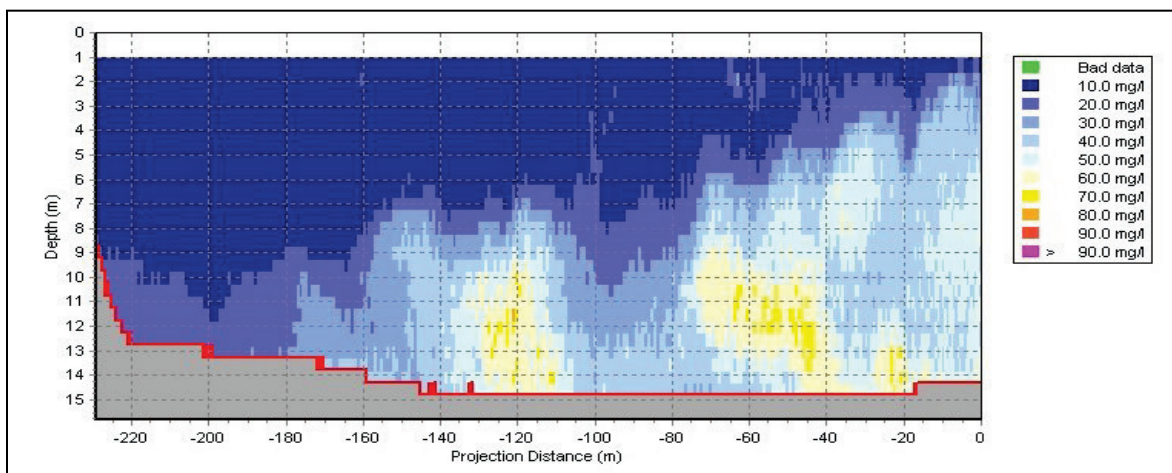


Figure 40. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 76 of the PEMT.

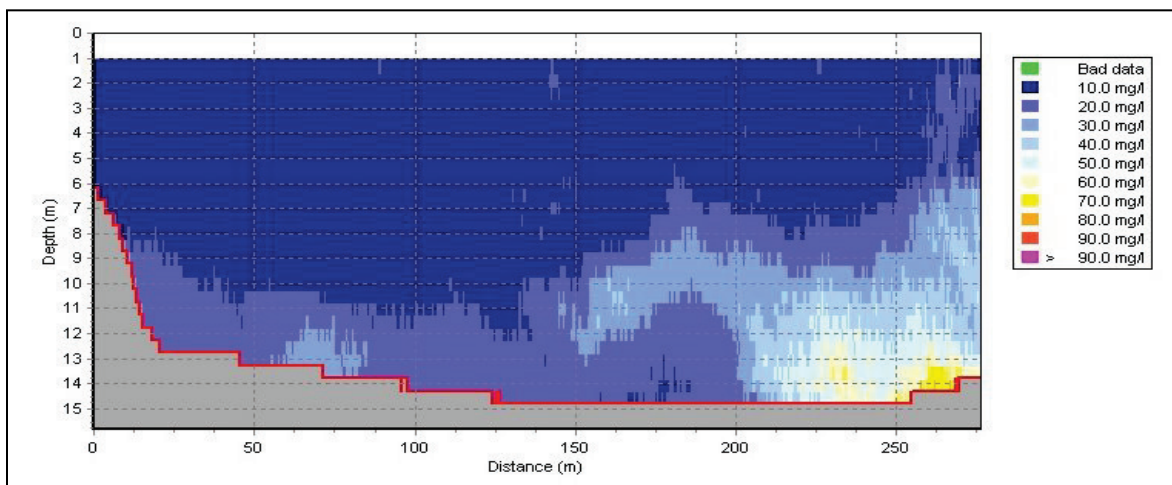
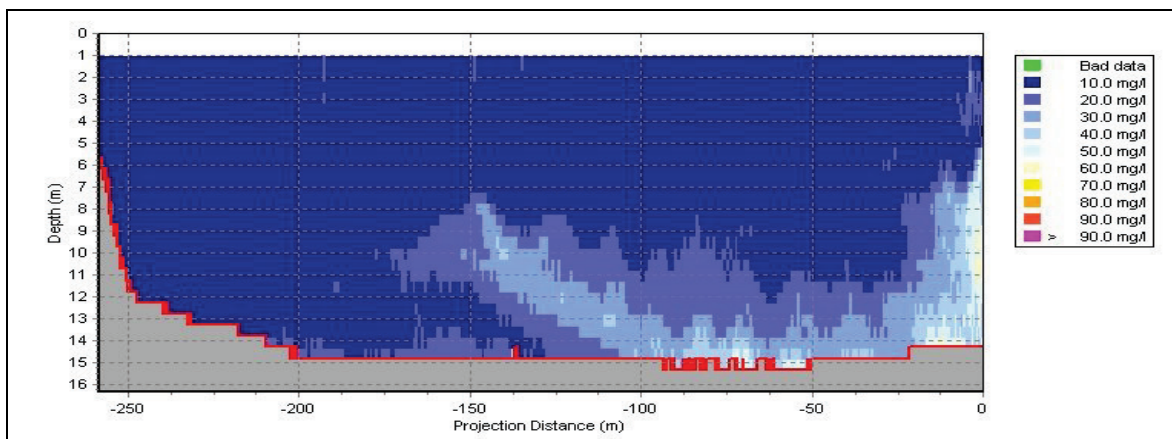


Figure 41. ADCP vertical profile running east to west (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 76 of the PEMT.



The plume created by the *Zim New York*, possibly superimposed on the residual plume of the *Zim Shenzhen*, decayed with increasing distance northward, initially influencing almost the entire water column before dissipating to a bottom feature approximately 200 m wide. The survey then turned southward to follow the plume's movement to the south with the ebbing tide. This set of transects (Figures 42-50) mapped a plume that extended at least 1.5 km to the south, with a weak plume signature still evident on the bottom of the final transect, which crossed the entire main navigation channel from just inside the South Elizabeth Channel to the shoal along the Bayonne shoreline. An interesting feature of the plume was its bifurcation into two distinct plumes approaching the southern extent of the survey (Figures 47-50). This may represent divergent components of a single plume due to water current circulation patterns, or perhaps the splitting of two plumes created by the passages of the *Zim Shenzhen* and *Zim New York* in succession.

Figure 42. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 76 of the PEMT.

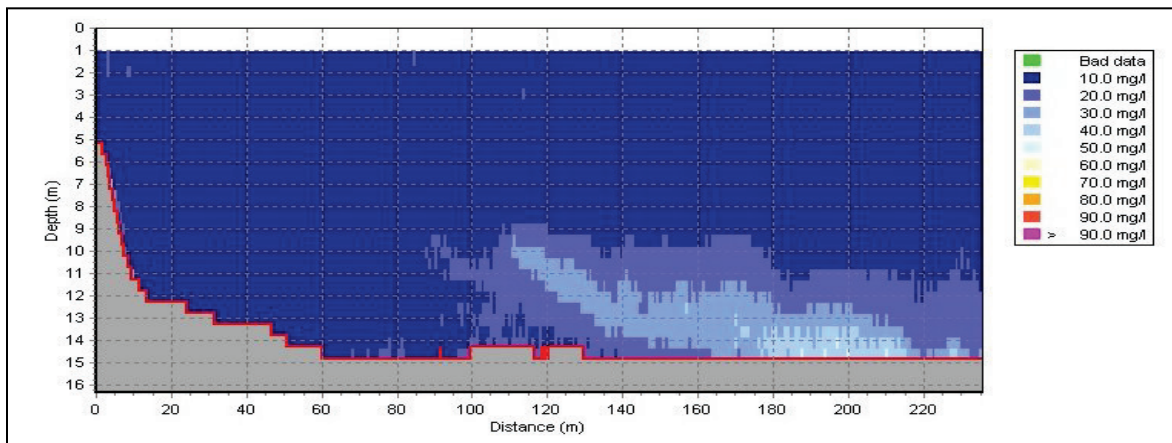


Figure 43. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*, ending at Berth 76 of the PEMT.

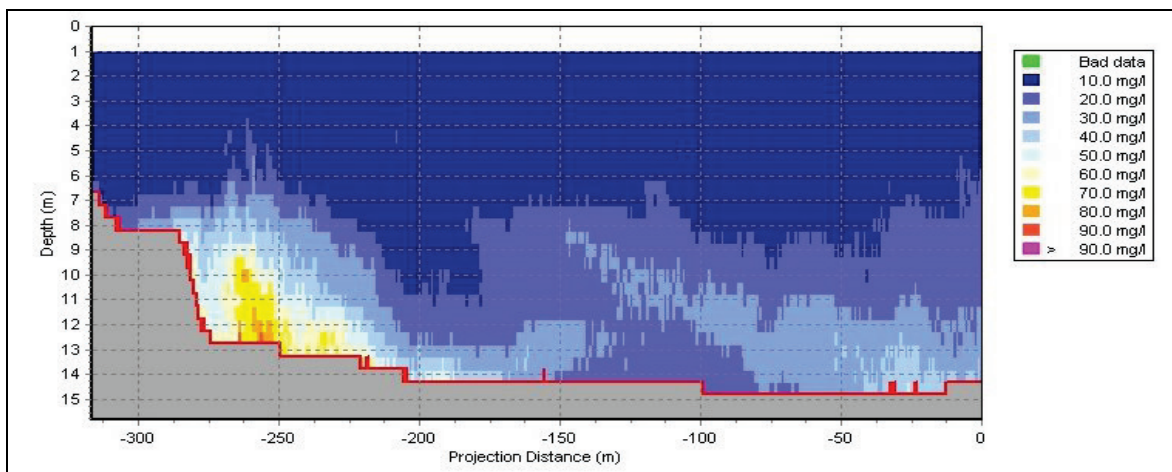


Figure 44. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

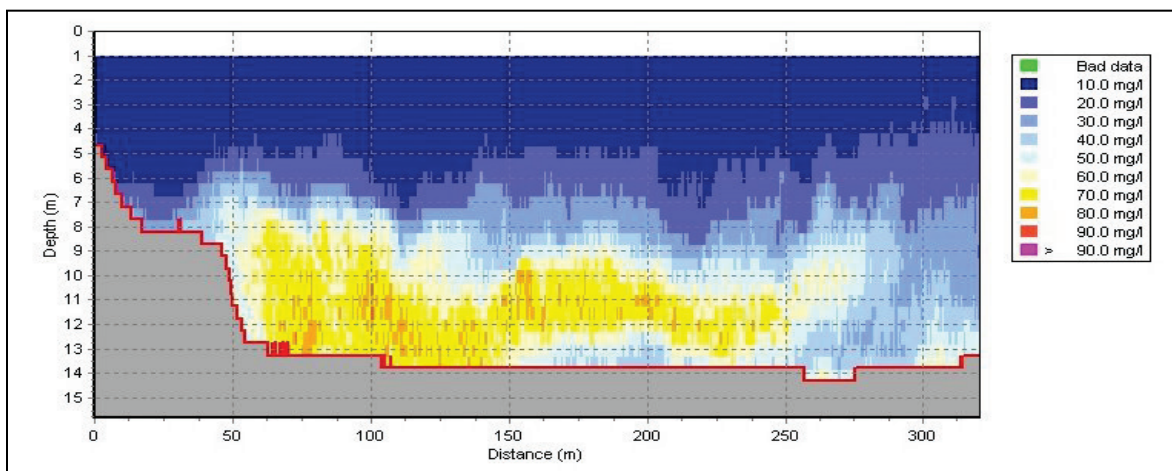


Figure 45. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

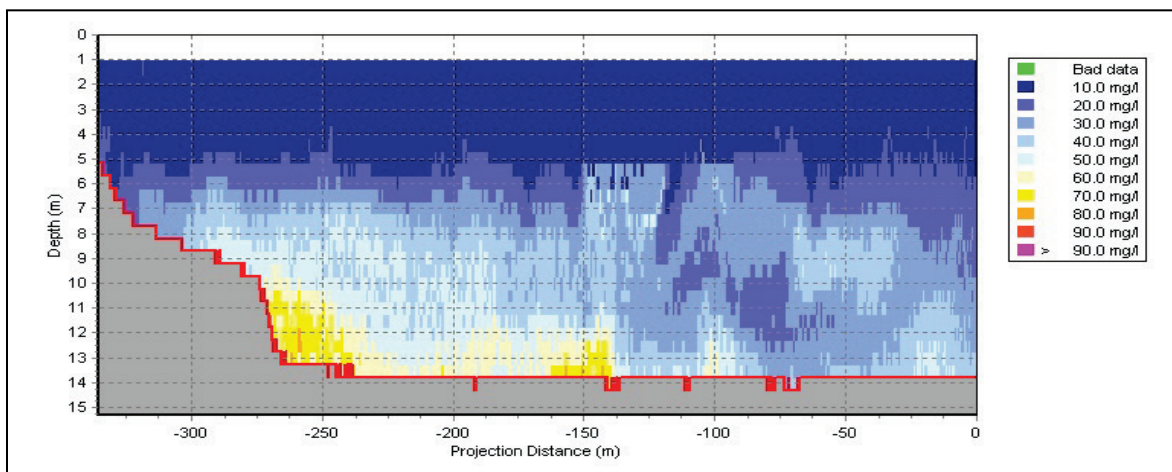


Figure 46. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

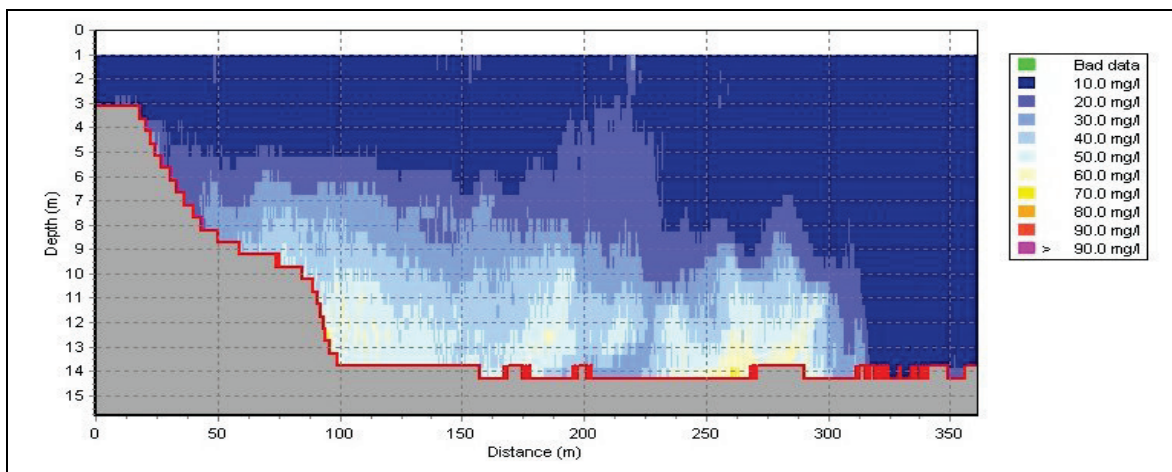


Figure 47. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

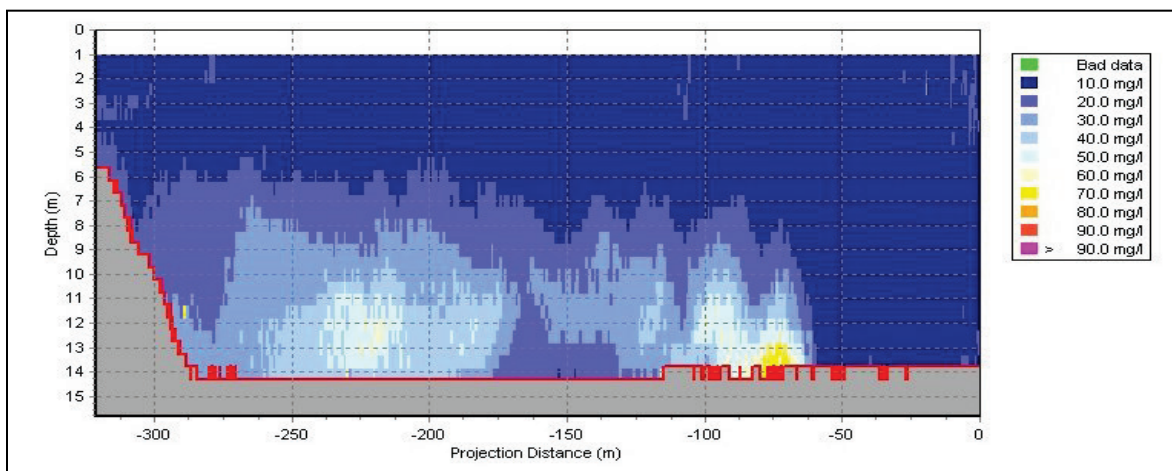


Figure 48. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

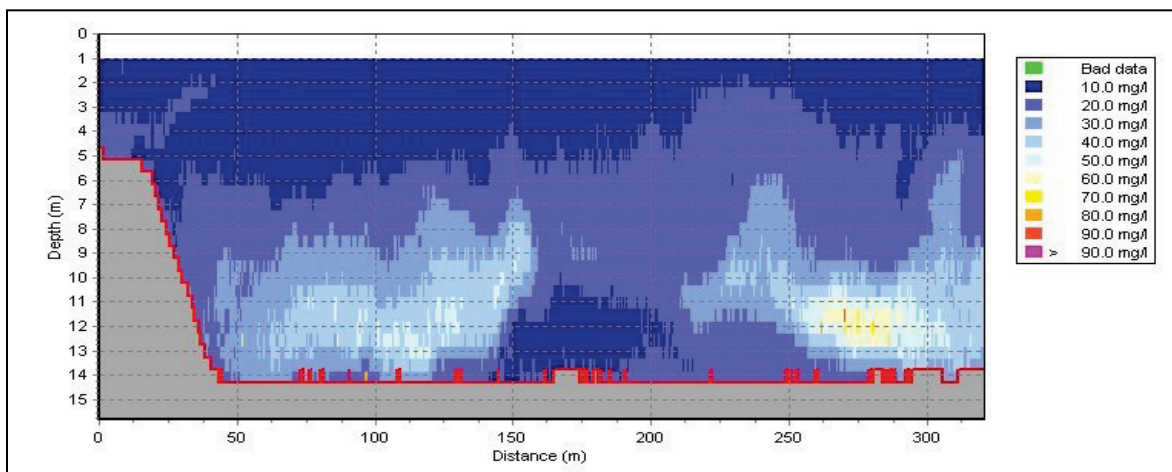


Figure 49. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.

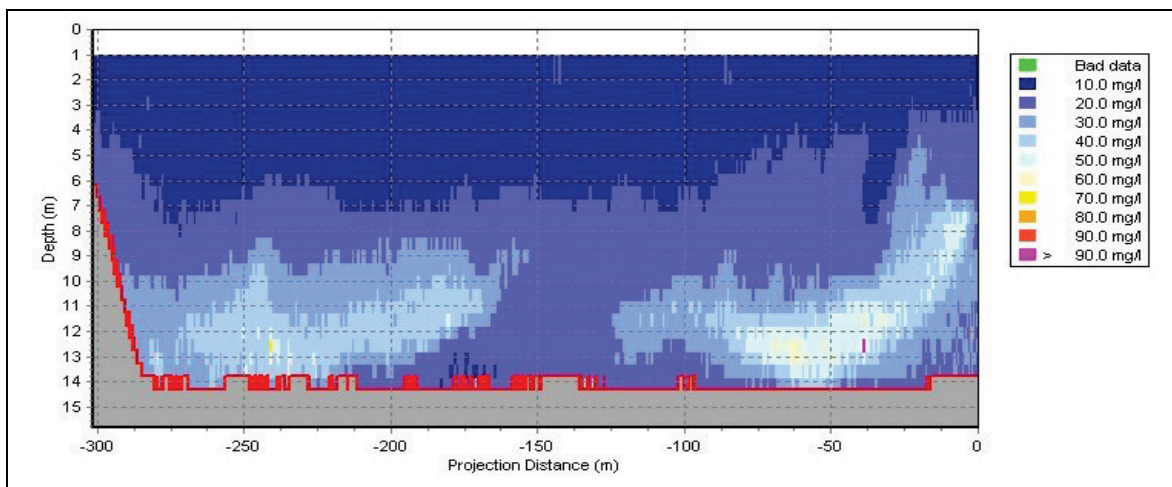
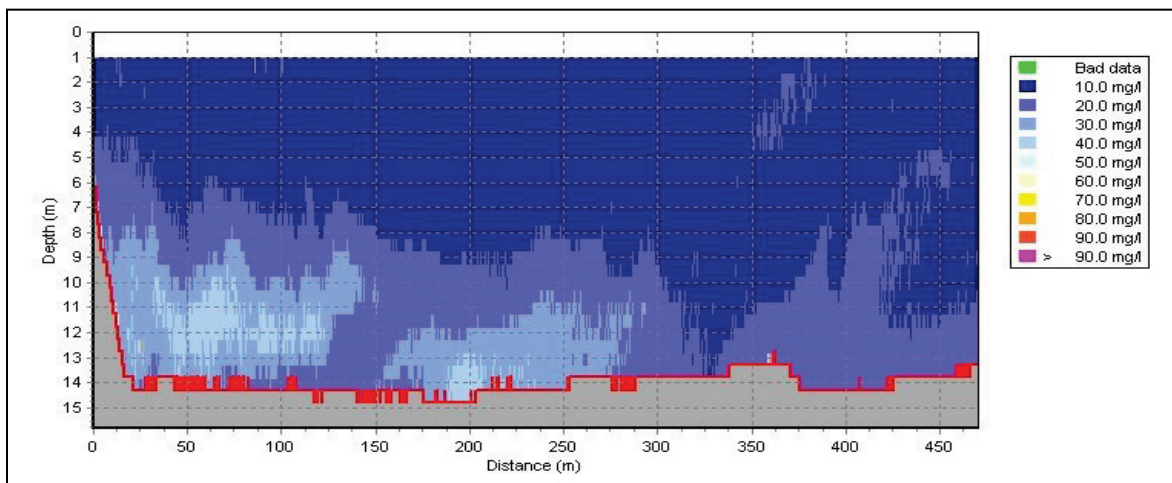


Figure 50. ADCP vertical profile running west to east (left to right) through plume created by passage of the container ship *Zim New York*.



On 23 November, the container ship *APL Turquoise* entered Newark Bay at approximately 1045 hr during a flooding tide (Figure 51) to eventually dock on the north bulkhead of the Elizabeth Channel (Figure 52). Arrival of the *APL Turquoise* was quickly followed by arrival of the Roll-On-Roll-Off (RORO) car carrier *Atlantic Concert* (Figure 53) at approximately 1110 hr. Three zig-zag transects were completed in advance of the ships' passage. The *APL Turquoise* took a more westerly path up the main navigation channel before maneuvering to enter the Elizabeth Channel, whereas the *Atlantic Concert* proceeded further north before turning into the Port Newark Channel. Aerial photographs of the wake of the *Atlantic Concert* (Figures 54 and 55) clearly show the plume of sediment brought to the surface by the prop-wash.

Figure 51. *APL Turquoise* inbound to Port Elizabeth Berth 53 on 24 January 2007.



Figure 52. Aerial view of surface plumes created by docking maneuvers of the *APL Turquoise*, with distinct lateral plume caused by bow thrusters evident in the foreground (courtesy of the PANYNJ).

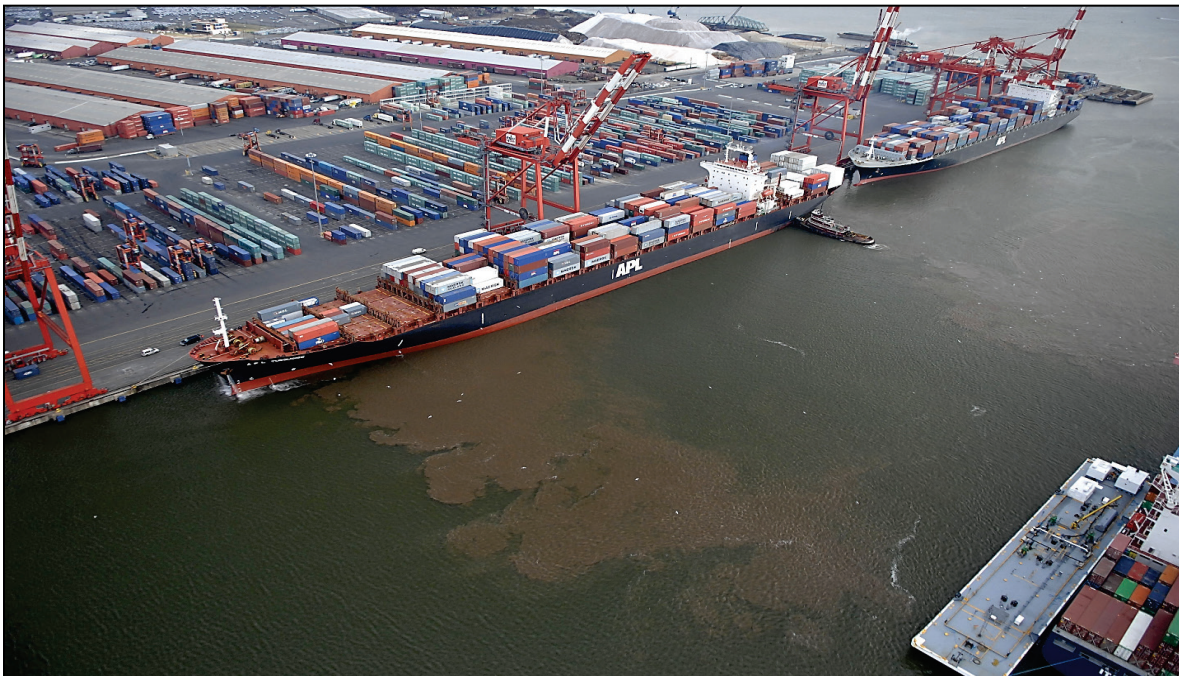


Figure 53. The Roll-On-Roll-Off car carrier, *ACL Atlantic Concert*, inbound to Port Newark on 24 January 2007.



Figure 54. Aerial photograph of the suspended sediment plume in the wake of the *Atlantic Concert* approaching the Port Newark Channel (courtesy of the PANYNJ).

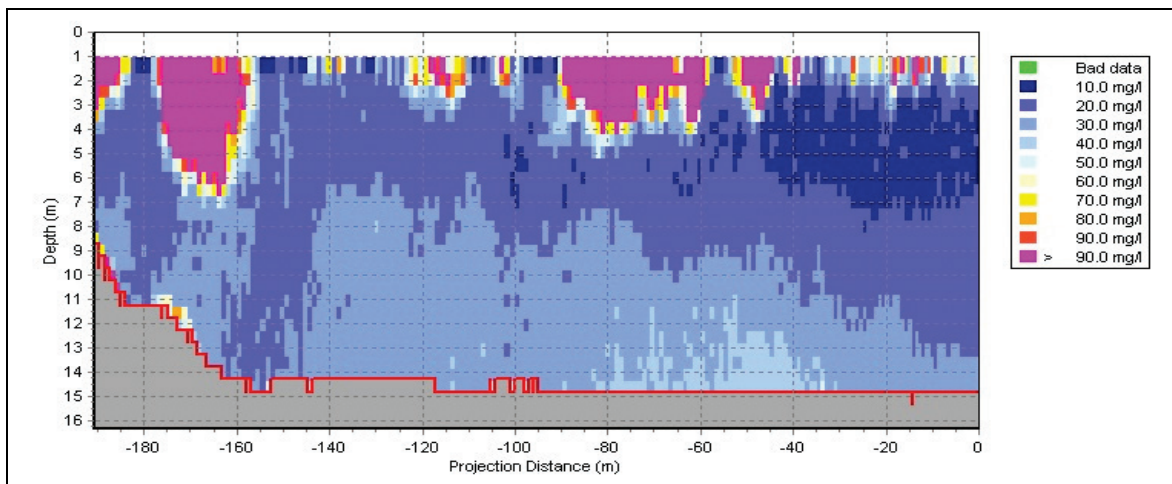


Figure 55. Aerial photograph of the suspended sediment plume in the wake of the *Atlantic Concert* entering the Port Newark Channel (courtesy of the PANYNJ).



An ADCP survey began at approximately 1100 hr, following a zig-zag course up-bay behind the two ships. Several transects were completed before passage of the two vessels (e.g., Figure 56), with indications of relatively high “ambient” conditions and surface prop-wash from passing tugs and barges. High ambient TSS concentrations may have been the result of resuspension by an earlier outbound container ship. The flooding tide could have retained a residual plume within the confines of the bay.

Figure 56. ADCP vertical profile prior to passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.



After passage of both ships, the survey continued northward as far as the confluence with the Port Newark Channel, where several additional transects were occupied running westward into Port Newark behind the *Atlantic Concert* (Figures 57 through 67). The most prominent plume was detected where the *Atlantic Concert* had turned into Port Newark (Figures 64 and 65).

Figure 57. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.

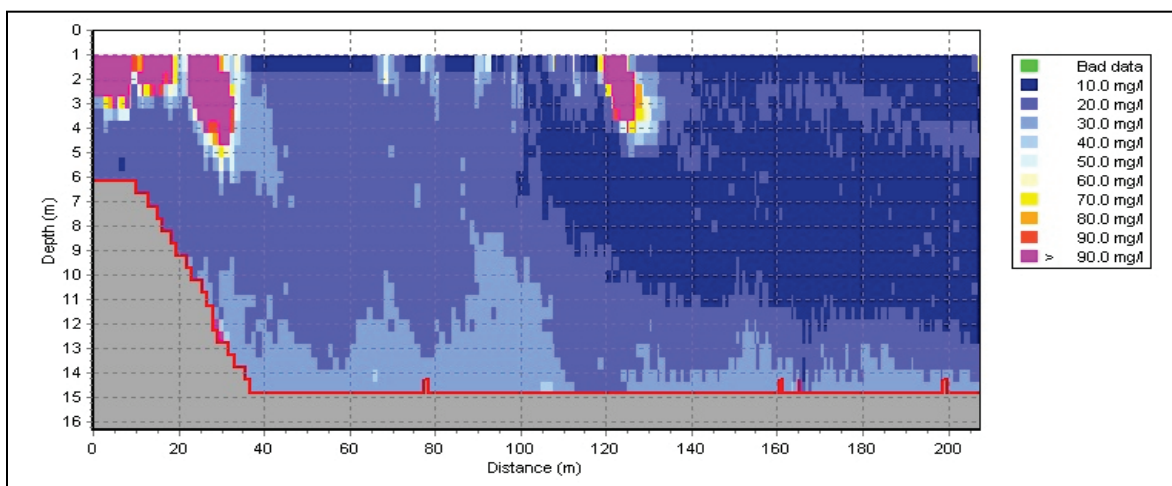


Figure 58. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.

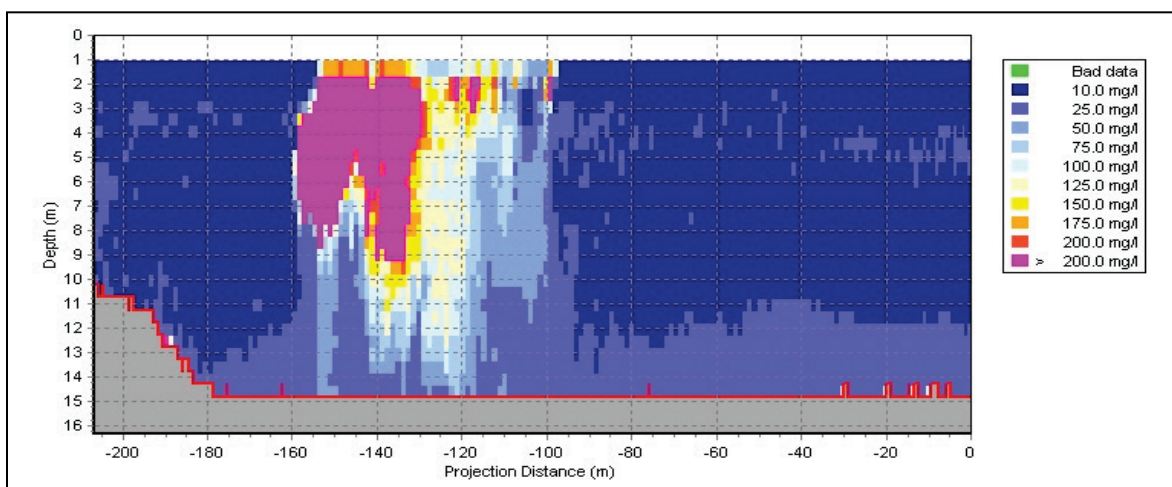


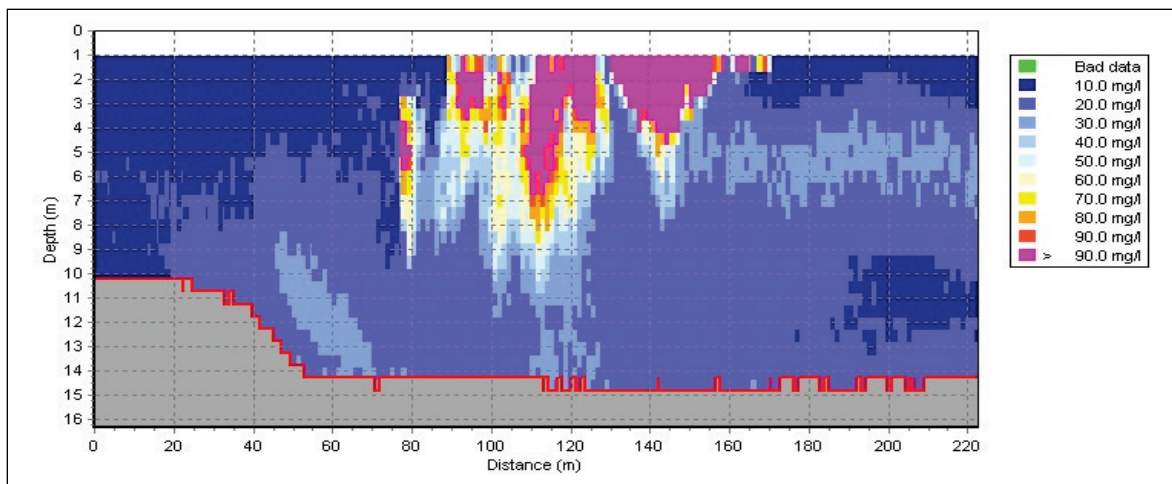
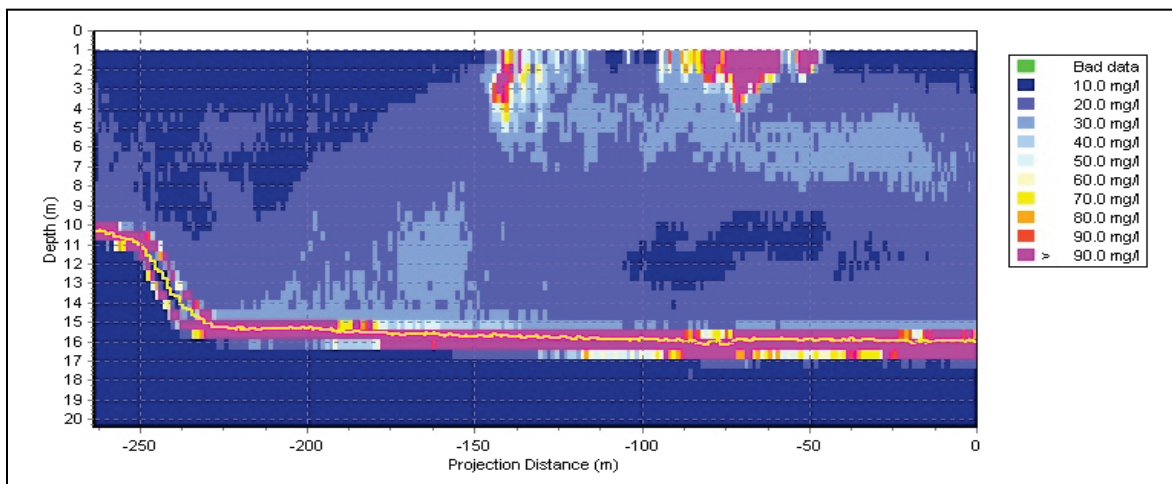
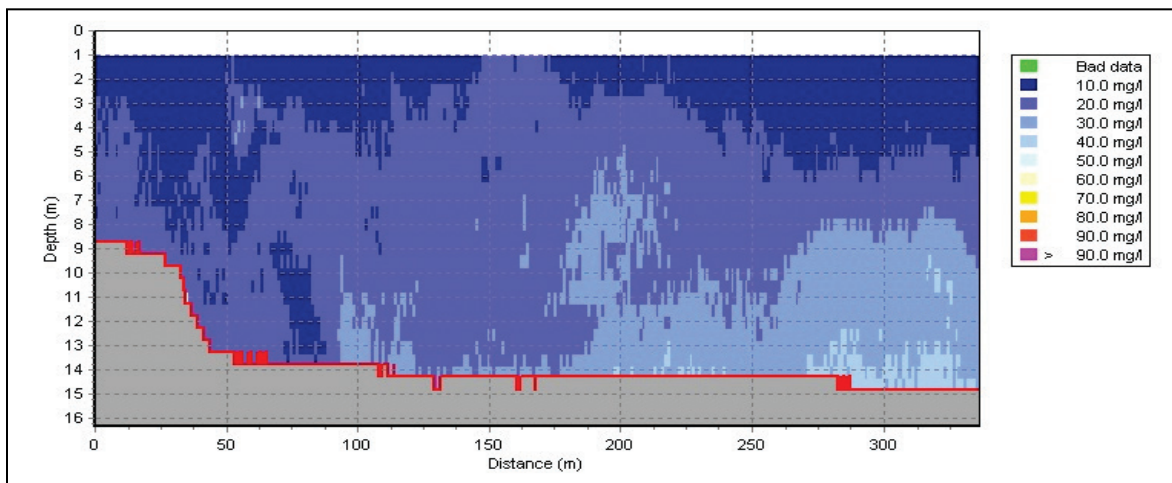
Figure 59. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 60. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 61. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.

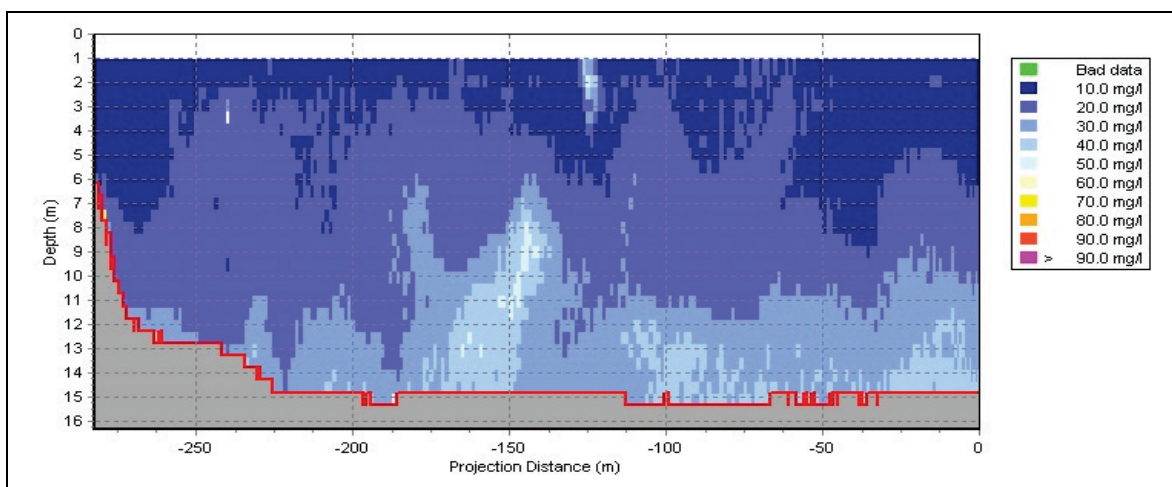
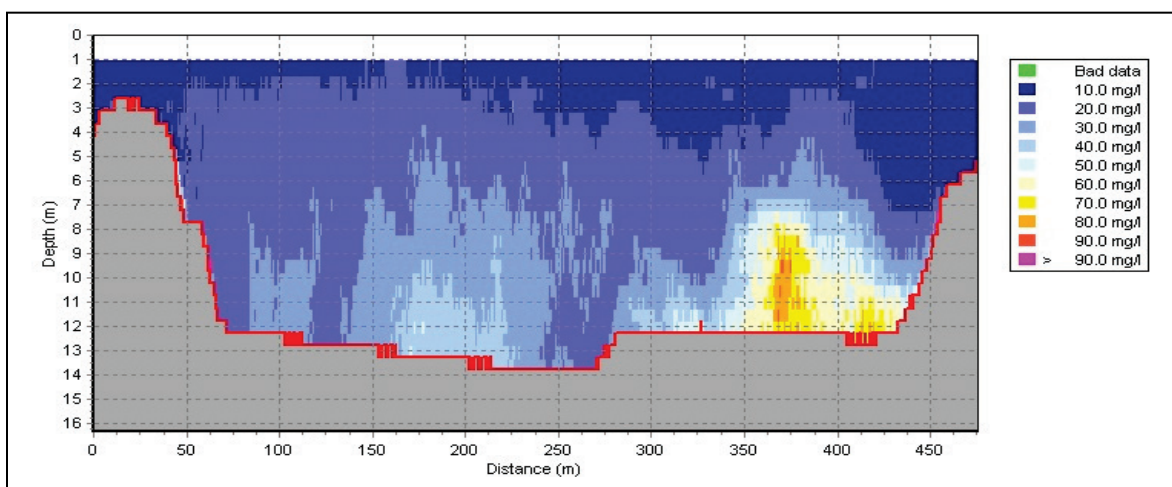
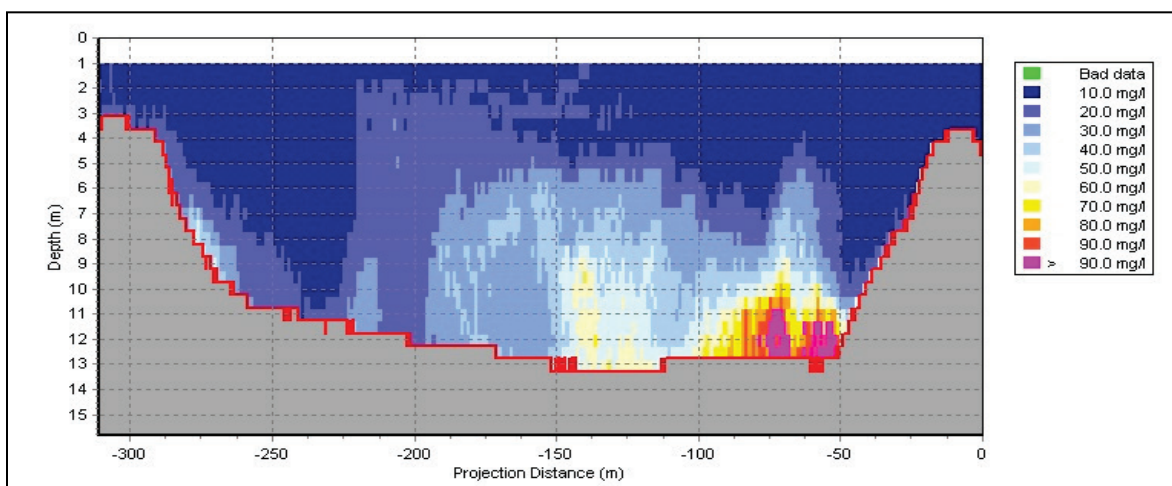
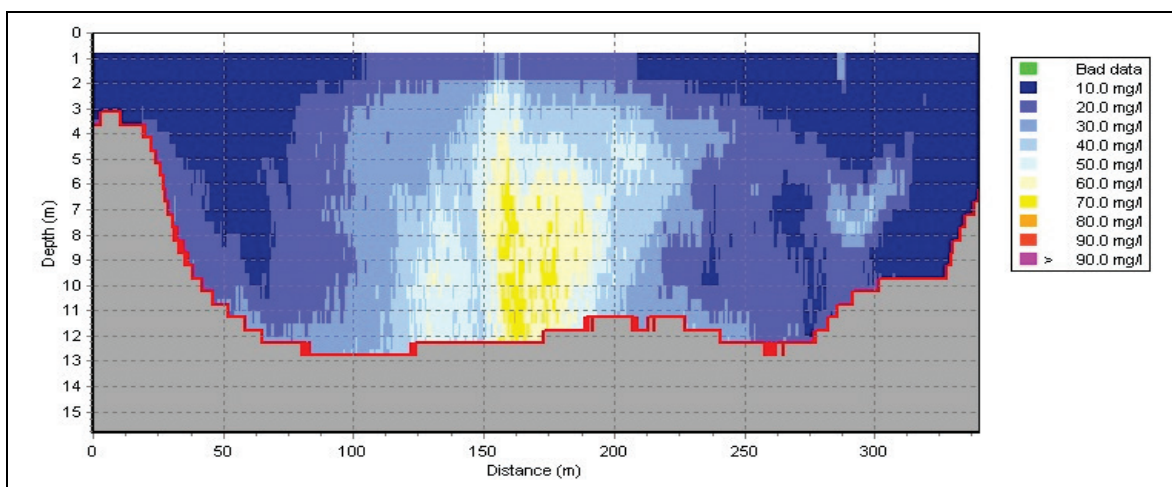
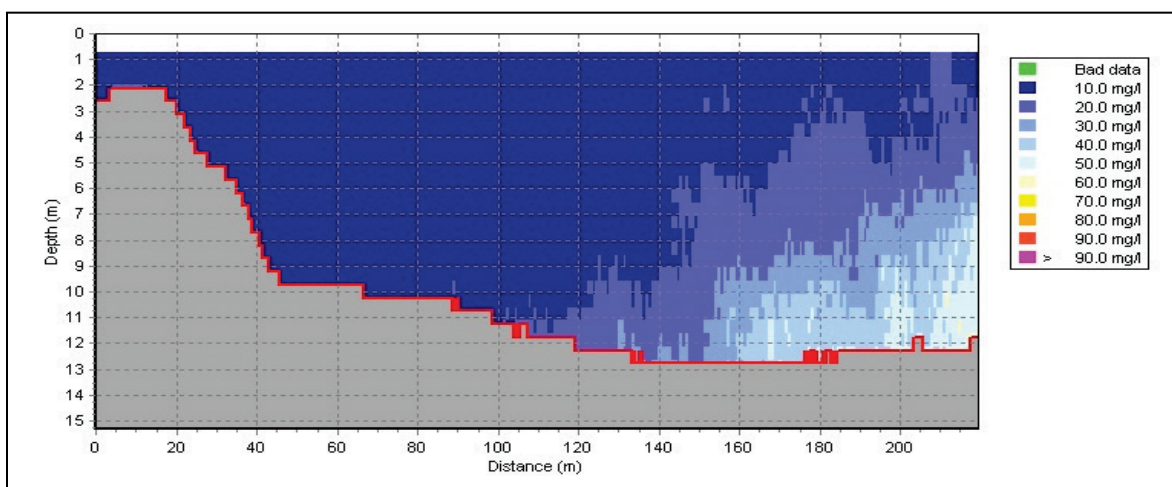
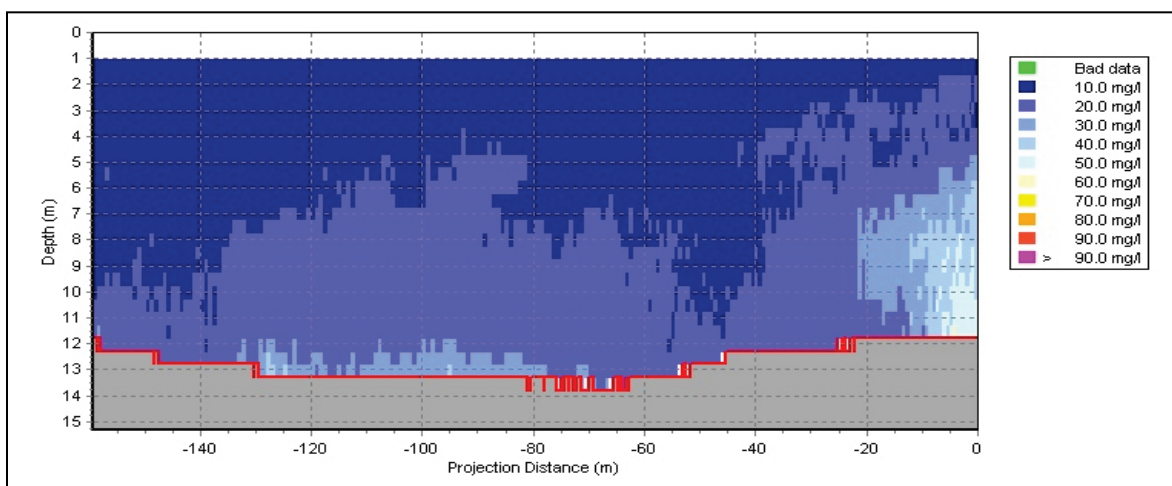
Figure 62. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 63. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 64. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.

Figure 65. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 66. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.Figure 67. ADCP vertical profile following passage of the *APL Turquoise* and *Atlantic Concert* in Newark Bay.

On 24 November, the container ship *APL Egypt* departed Port Elizabeth during an ebbing tide (Figures 68 and 69) at approximately 1600 hr. The survey consisted of two sets of transects; the first comprised of zig-zag transects following the *APL Egypt* as it backed out of the Elizabeth Channel (Figures 70 to 79), followed by a series of transects crossing the area in which the ship rotated to face southward (Figures 80 to 88). A prominent prop-wash/plume signature was present in the Elizabeth Channel adjacent to Berth 61 where the ship was pulled from the dock by an attending tug. The plume dissipated quickly as the ship was slowly backed out of the Elizabeth Channel. Tug prop-wash is visible at the surface along several transects.

A second prominent prop-wash/plume signature was detected along a transect crossing the turning area in open waters of Newark Bay (Figure 81). The survey vessel then moved south to try to get in front of the plume being carried by the ebbing tide, and then zig-zagged in a northerly direction. A distinct plume signature was found along the eastern side of the main navigation channel, as evident in Figures 84 to 87.

Figure 68. The container ship *APL Egypt* departing Port Elizabeth.



Figure 69. The container ship *APL Egypt* departing Port Elizabeth.



Figure 70. ADCP vertical profile of ambient conditions in the Elizabeth Channel prior to departure of the container ship *APL Egypt* during an ebbing tide.

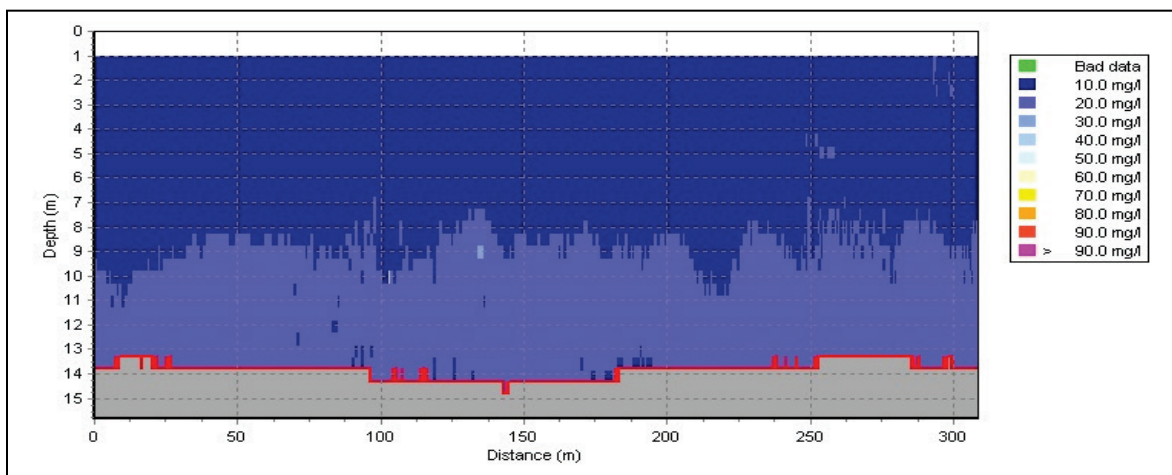


Figure 71. ADCP vertical profile in the Elizabeth Channel 513 m from the bow of the container ship *APL Egypt* as the ship backed toward Newark Bay.

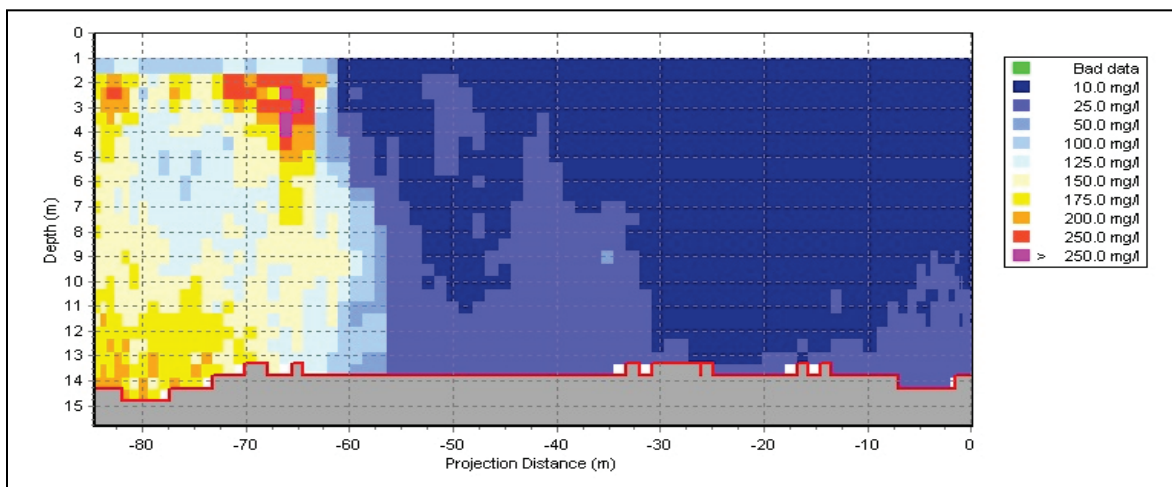


Figure 72. ADCP vertical profile in the Elizabeth Channel 598 m from the bow of the container ship *APL Egypt* as the ship backed toward Newark Bay.

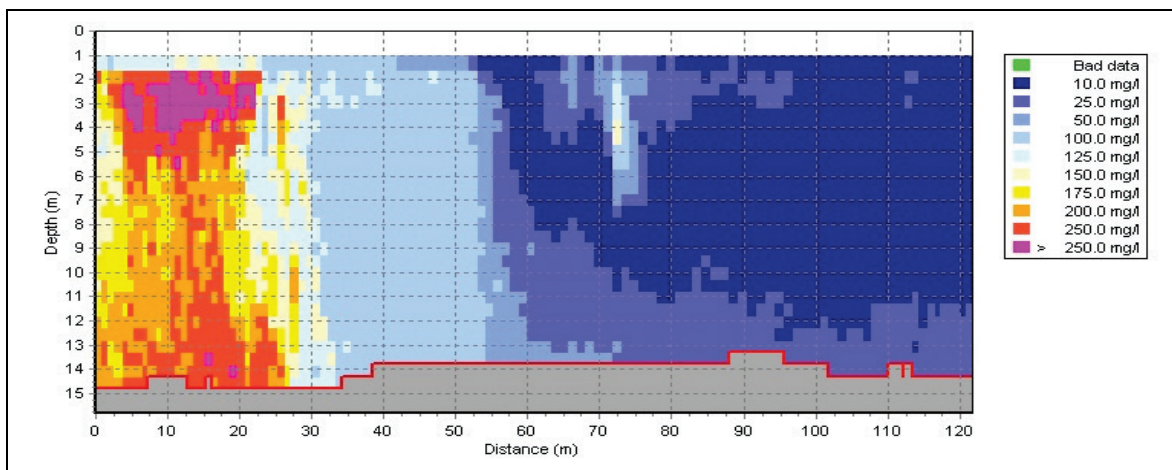


Figure 73. ADCP vertical profile in the Elizabeth Channel 750 m from the bow of the container ship *APL Egypt* as the ship backed toward Newark Bay.

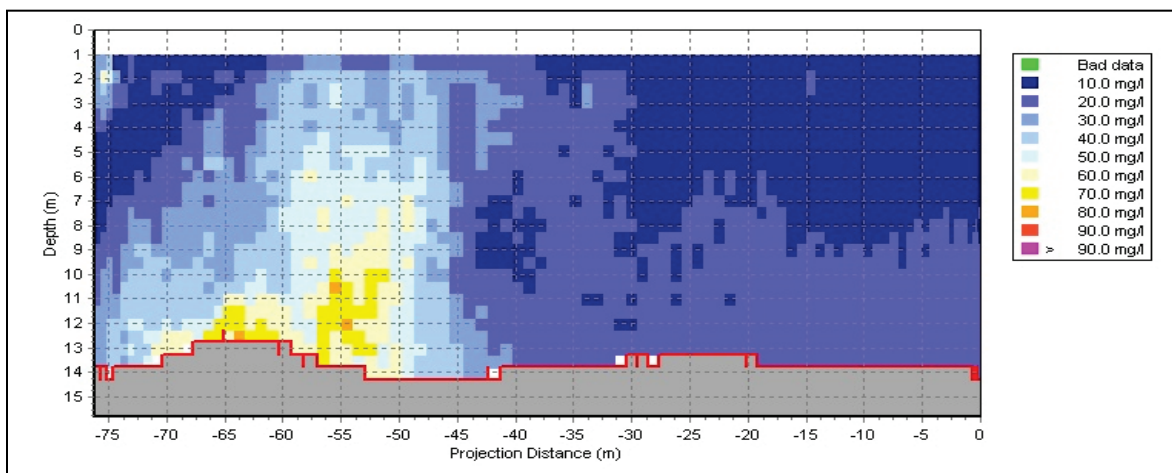


Figure 74. ADCP vertical profile in the Elizabeth Channel 815 m from the bow of the container ship *APL Egypt* as the ship backed toward Newark Bay.

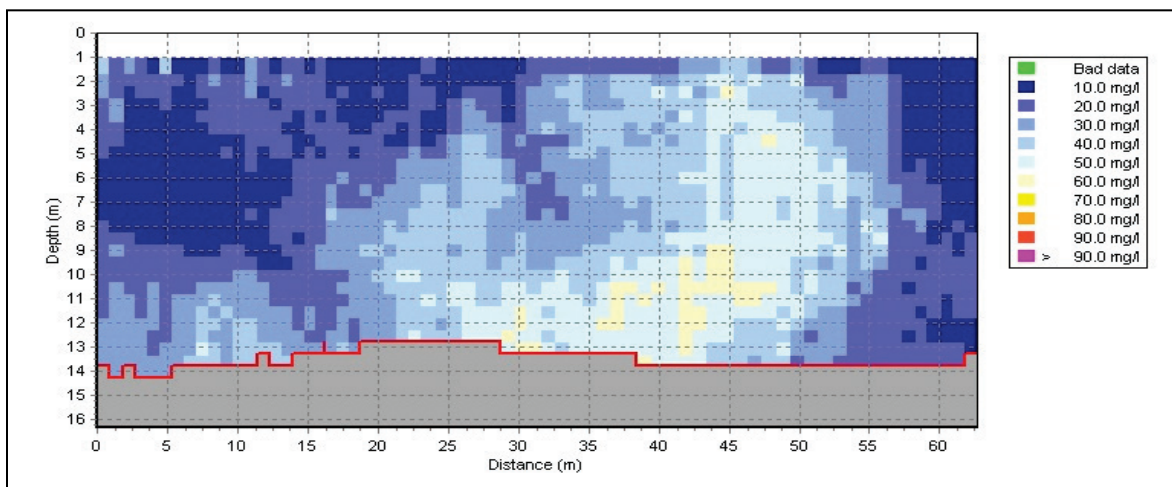


Figure 75. ADCP vertical profile in the Elizabeth Channel 868 m from the bow of the container ship *APL Egypt* as the ship backed toward Newark Bay.

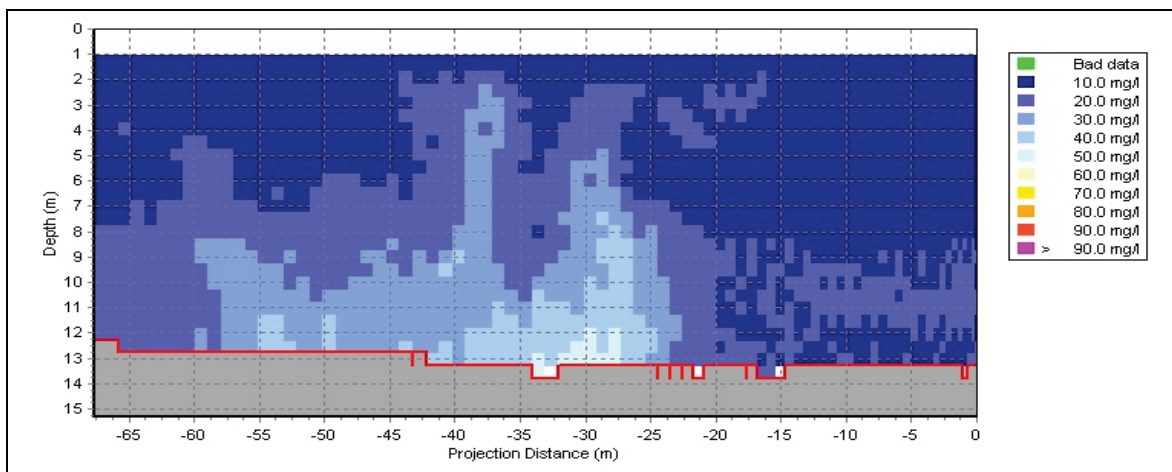


Figure 76. ADCP vertical profile in the Elizabeth Channel 872 m from the bow of the container ship *APL Egypt* as the ship entered Newark Bay.

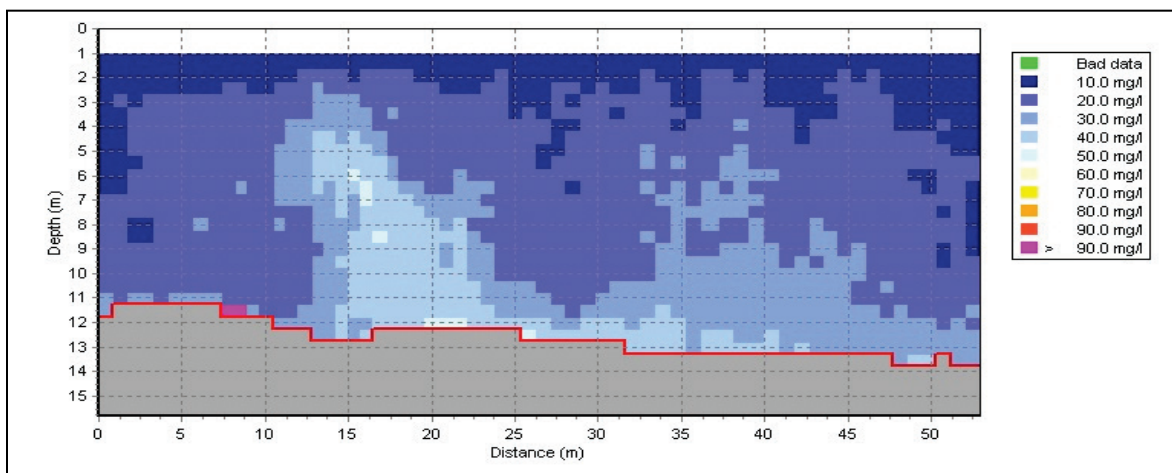


Figure 77. ADCP vertical profile in the Elizabeth Channel 1,005 m from mid-ship point of the container ship *APL Egypt* as the ship rotated southward in Newark Bay.

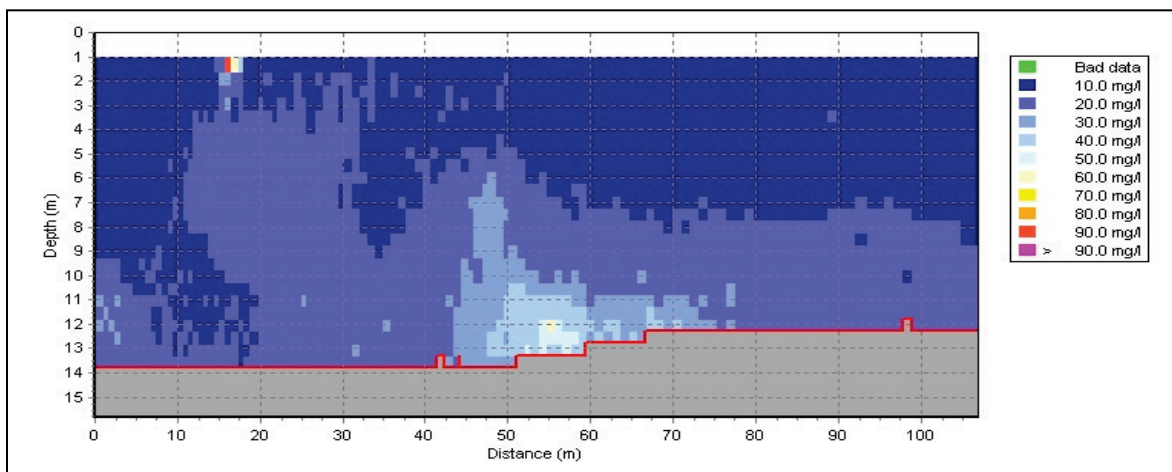


Figure 78. ADCP vertical profile in the Elizabeth Channel 760 m from mid-ship point of the container ship *APL Egypt* as the ship rotated southward in Newark Bay.

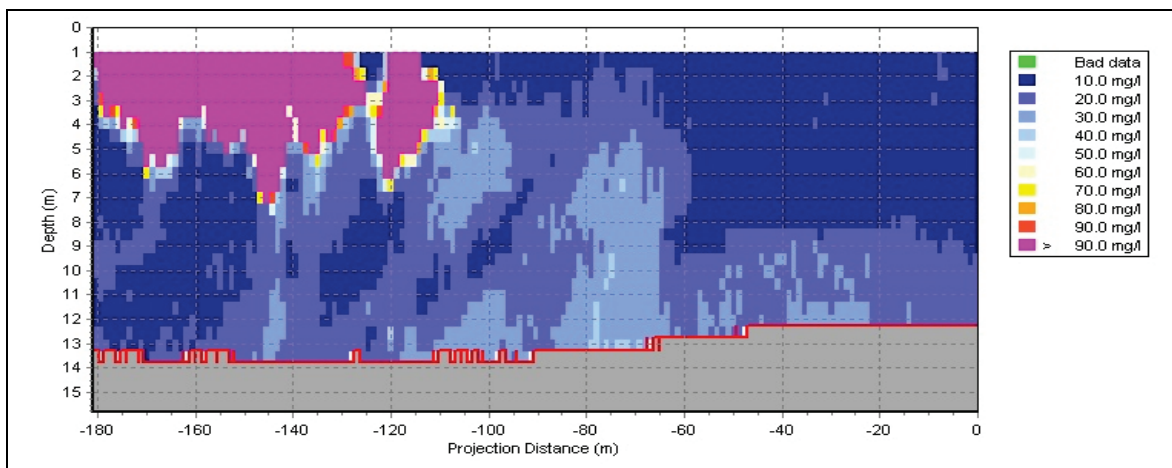


Figure 79. ADCP vertical profile in the Elizabeth Channel 500 m from the mid-ship point of the container ship *APL Egypt* as the ship backed toward Newark Bay.

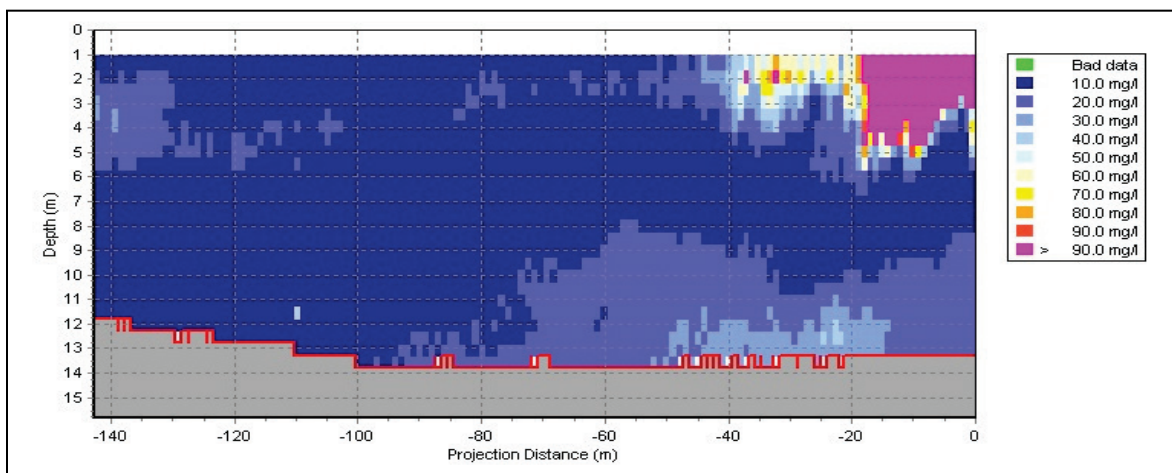


Figure 80. ADCP vertical profile in the Elizabeth Channel 830 m from the mid-ship point of the container ship *APL Egypt* as the ship backed toward Newark Bay.

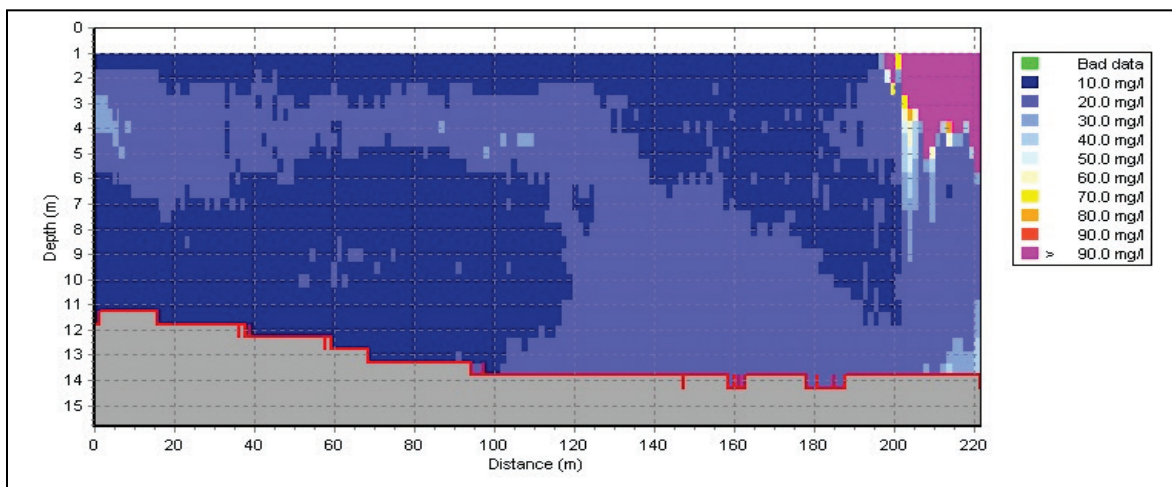


Figure 81. ADCP vertical profile across turning areas following rotation of the container ship *APL Egypt* as it began moving toward the Bayonne Bridge. Distance to ship 945 m.

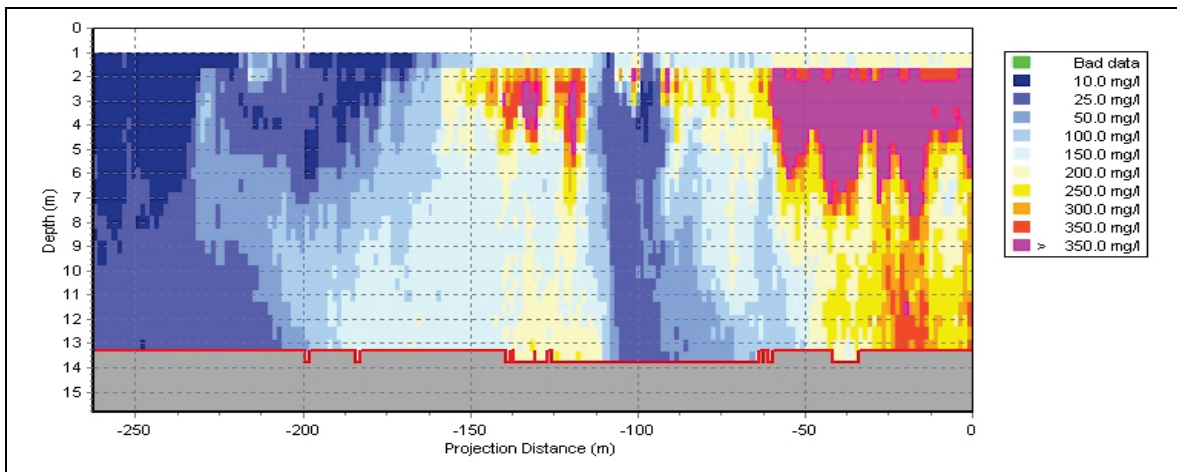


Figure 82. ADCP vertical profile across main navigation channel opposite Berth 86 as the container ship *APL Egypt* moved toward the Bayonne Bridge.

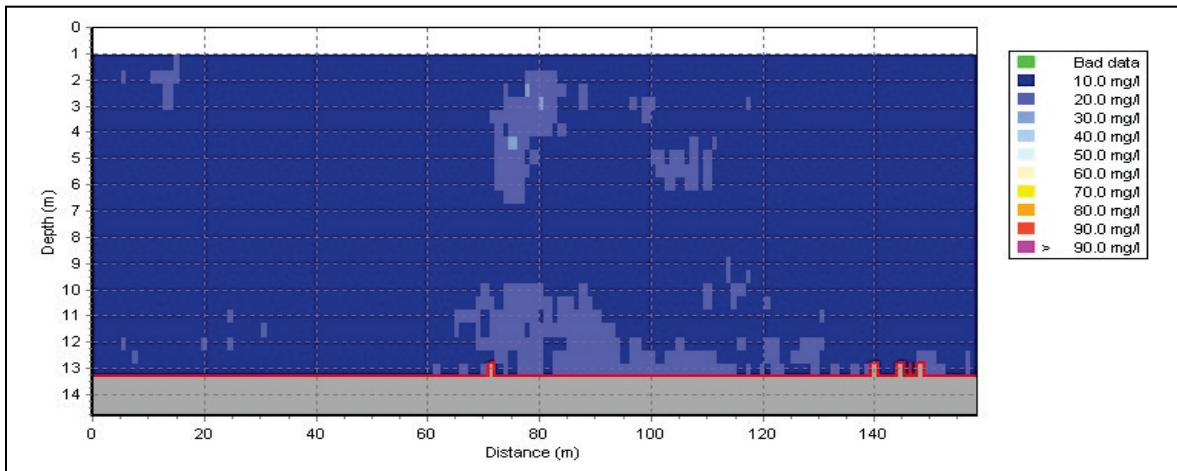


Figure 83. ADCP vertical profile in the main navigation channel as the container ship *APL Egypt* moved toward the Bayonne Bridge. Distance to ship 935 m.

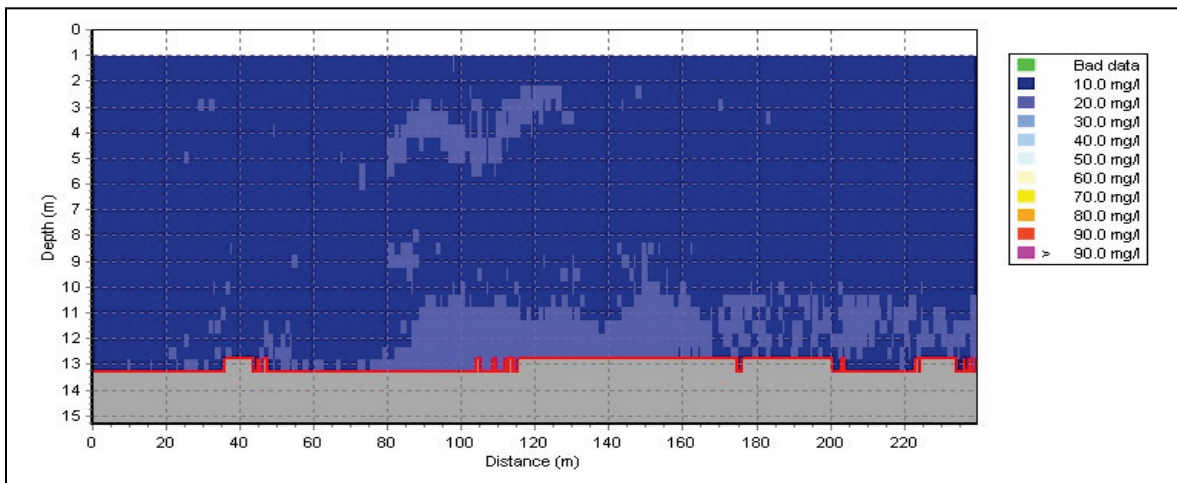


Figure 84. ADCP vertical profile from east to west (left to right) across the main navigation channel opposite Berth 80 approximately 35 min after departure of *APL Egypt*.

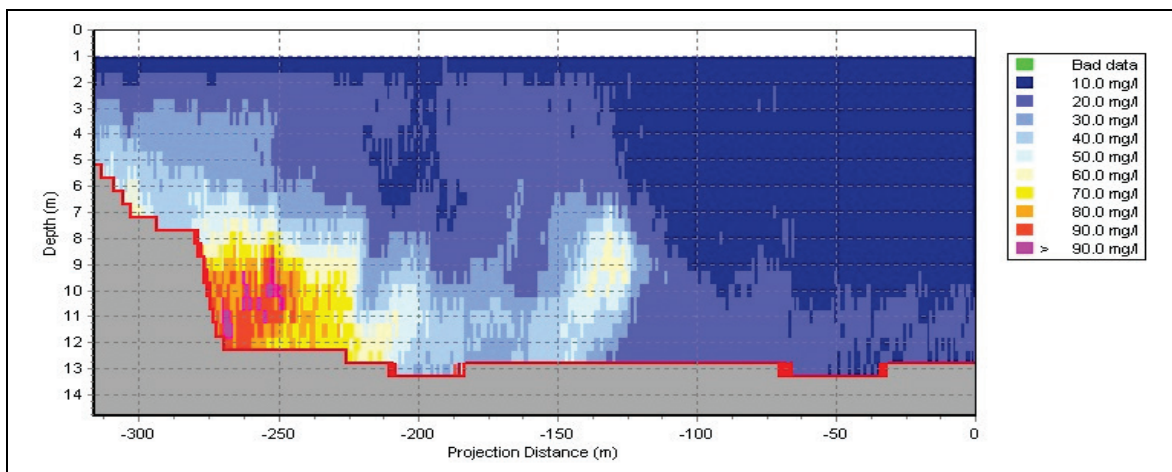


Figure 85. ADCP vertical profile from east to west (left to right) across the main navigation channel opposite Berth 80 approximately 40 min after departure of the *APL Egypt*.

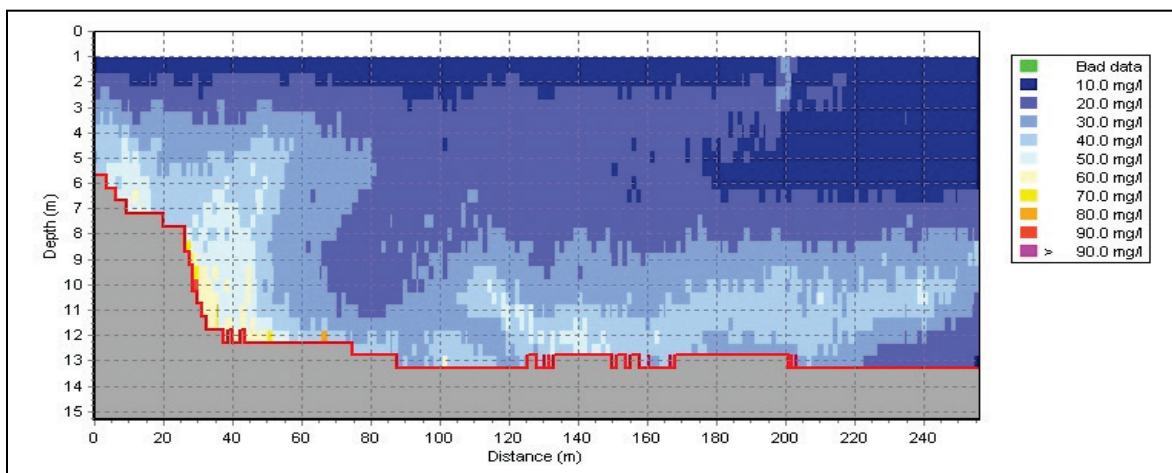


Figure 86. ADCP vertical profile from east to west (left to right) across the main navigation channel opposite Berth 80 approximately 38 min after departure of the *APL Egypt*.

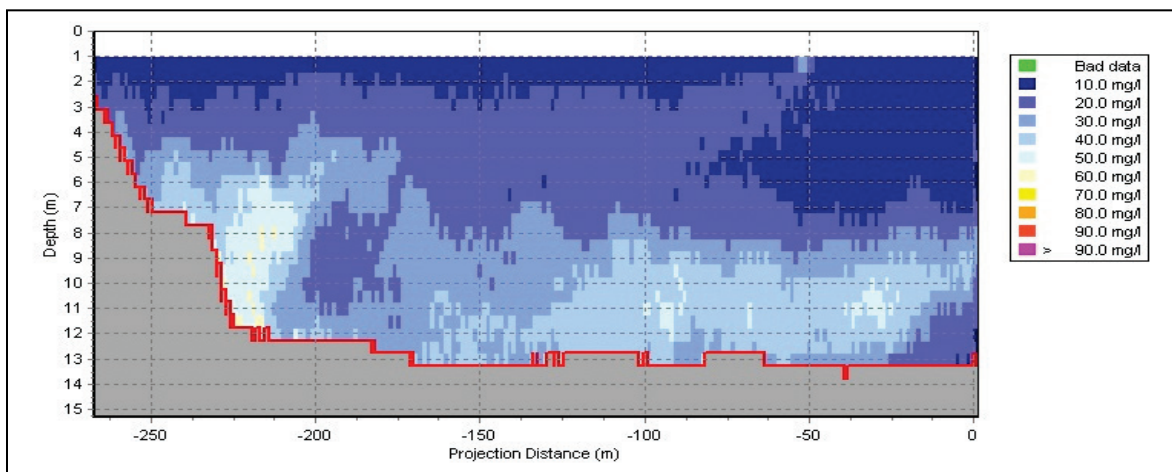


Figure 87. ADCP vertical profile from east to west (left to right) across the main navigation channel opposite Berth 80 approximately 42 min after departure of the *APL Egypt*.

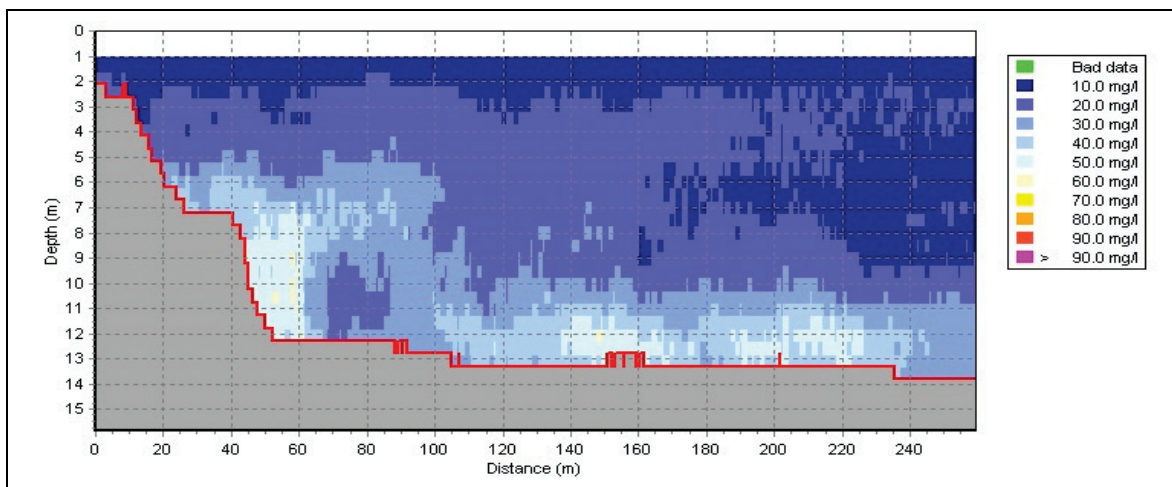
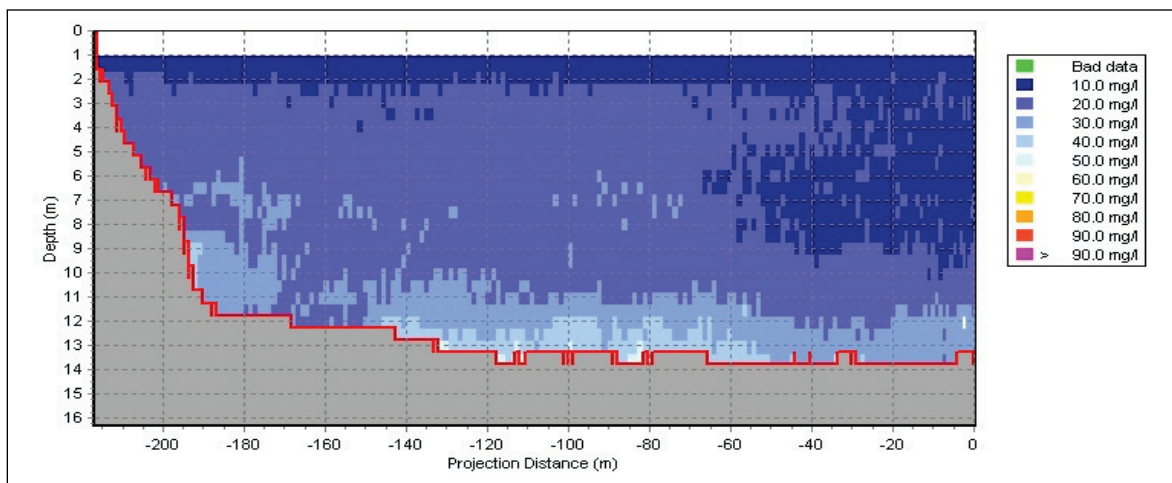


Figure 88. ADCP vertical profile from east to west (left to right) across the main navigation channel opposite Berth 80 approximately 46 min after departure of the *APL Egypt*.



November 2009 Ship Traffic Survey Series

This set of surveys occurred between 4th and 10th of November 2009, including a broad area survey of ambient conditions on November 5th. The container ship *Cosco Luobahe* (Figure 89) entered Newark Bay at approximately 1220 hr on November 4th during an ebbing tide. Three zig-zag transects to capture ambient conditions were completed before the *Luobahe* passed the location of the survey vessel, followed by four transects straddling the mid-bay location where the container ship was being maneuvered by tugs into a berth along the mid-section of the outer Port Elizabeth bulkhead.

Figure 89. The container ship *Cosco Luobahe* upon completion of docking maneuvers.



Transect 21 ran through the area immediately south of the ship as it began a 180-degree rotation to face southward. A prominent prop-wash effect is evident in Figure 90, and may represent forces exerted on the bottom by the tending tugs as well as the ship itself. At this point, the ship was applying reverse power to slow forward movement prior to being swung around. The left side of the ADCP vertical profile begins just east of the berthing area and extends eastward to the shipping channel basin. The acoustic signature resembling prop-wash on the right side of the figure actually represents effluent originating from a sewage treatment plant. This feature was consistently seen during ebbing tides, growing in size to the north. Ensuing ADCP transects on which ship-plume signatures were detected continued generally northward (Figures 91-94), revealing that the plume became concentrated along the Port Elizabeth outer bulkhead and persisted for at least 45 min.

A second set of transects began about one hour after the arrival of the *Cosco Luohabe* and 30 min after completion of the docking maneuvers. The survey consisted of eleven zig-zag transects beginning just south of the entrance to the Port Elizabeth Channel and ending with a transect that crossed Newark Bay running eastward from the northern edge of the flats at the entrance to the South Elizabeth Channel. The final transect was completed approximately 35 min after completion of the docking maneuvers. An ebbing tide continued to disperse the ship-induced plume to the south. The series of vertical profiles in Figures 95-98 depict evolution of the plume, which first became a wide, diffuse feature affecting almost the entire water column.

Figure 90. Bottom disturbance by prop-wash during berthing maneuvers of the container ship *Cosco Luobahe*, 435 m from the bow of the ship.

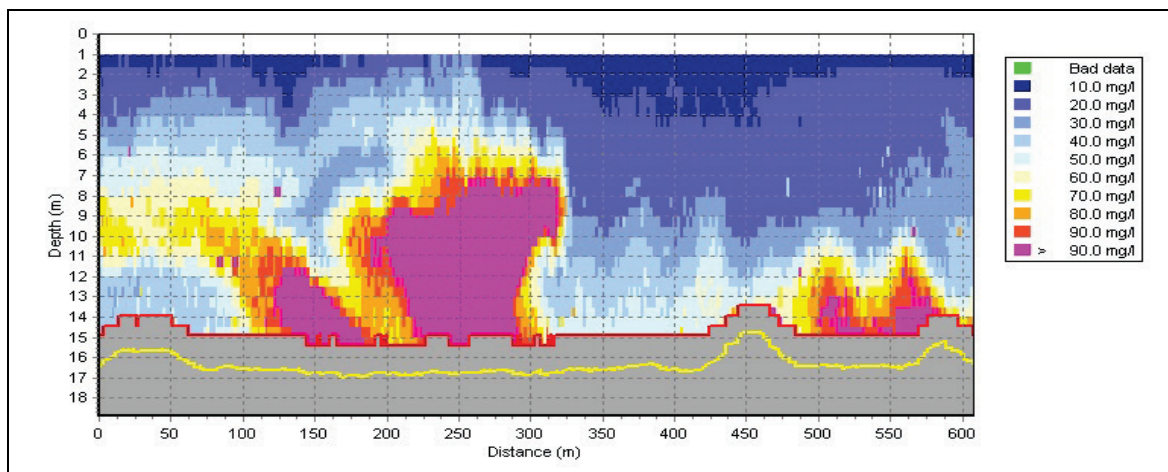


Figure 91. Prop-wash signature along the east (left) side of a transect located immediately north of the *Cosco Luobahe*, 75 m from the bow of the ship.

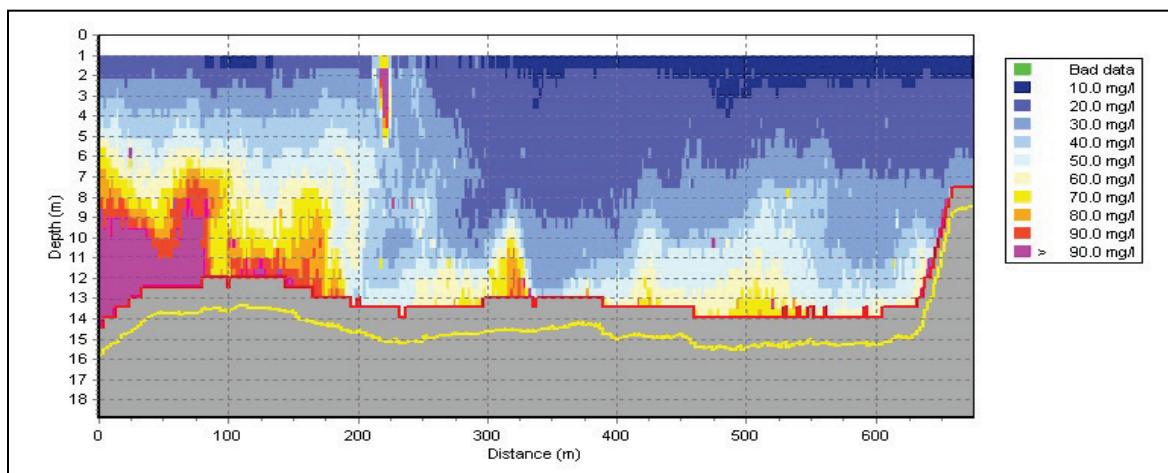


Figure 92. Transect from east to west with a ship plume signature (right side) at the stern of the moored *Cosco Luobahe*.

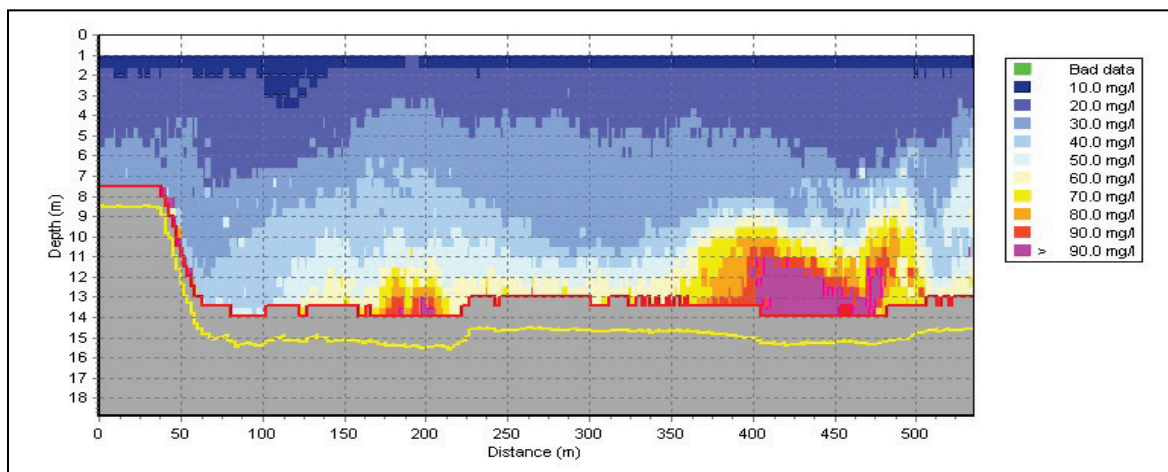


Figure 93. Transect from west to east, with a ship plume signature at the western end (left side), at a distance of 200m from the stern of the *Cosco Luobahe*.

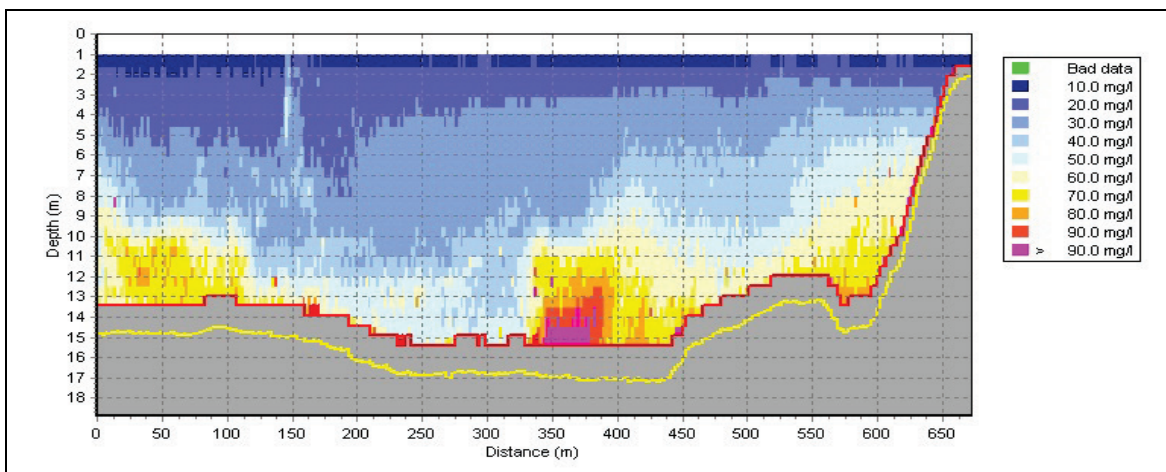


Figure 94. ADCP vertical profile moving eastward (left to right) at the stern of the *Cosco Luohabe* after completion of docking maneuvers.

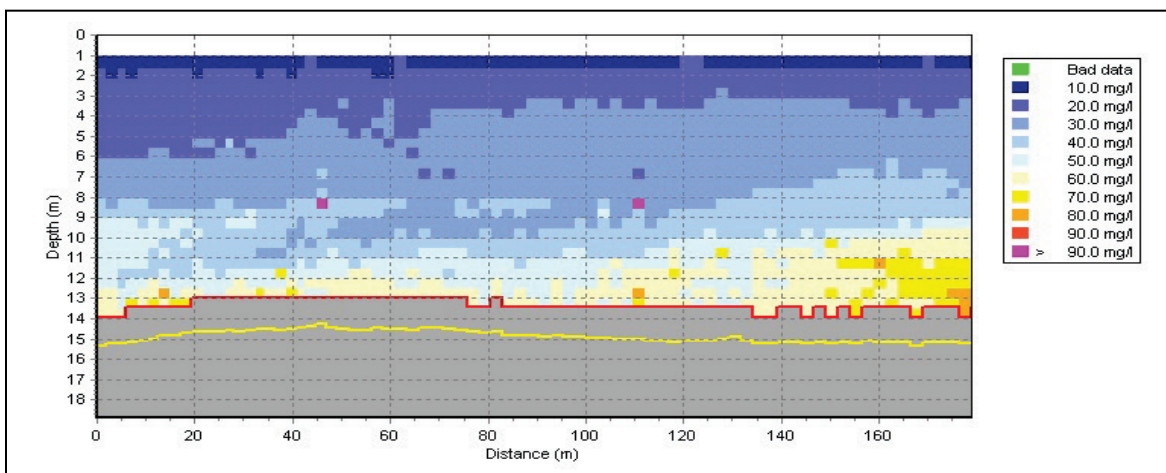


Figure 95. ADCP vertical profile moving eastward (left to right) beginning 20 m south of the bow of the *Cosco Luohabe* after completion of docking maneuvers.

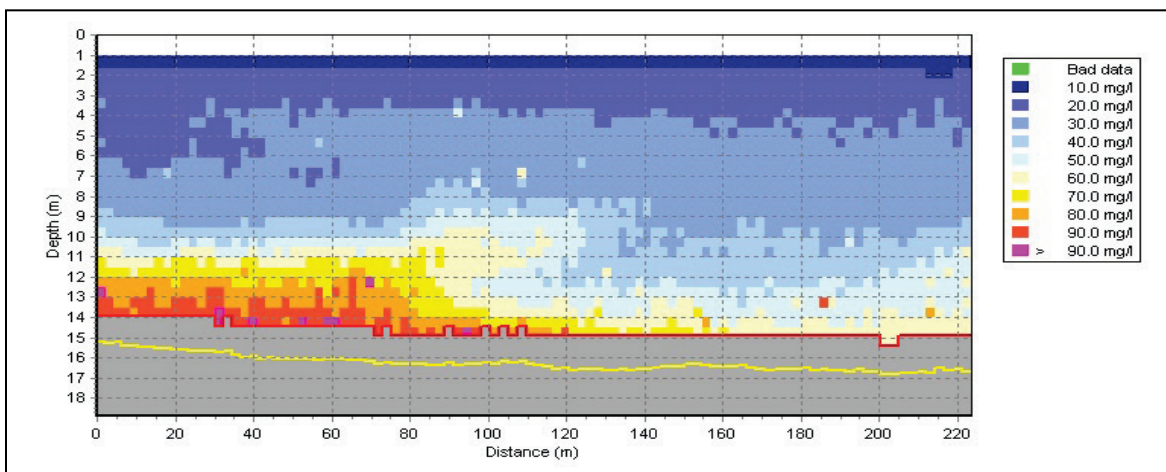


Figure 96. ADCP vertical profile moving eastward (left to right) beginning 445 m south of the bow of the *Cosco Luohabe* after completion of docking maneuvers.

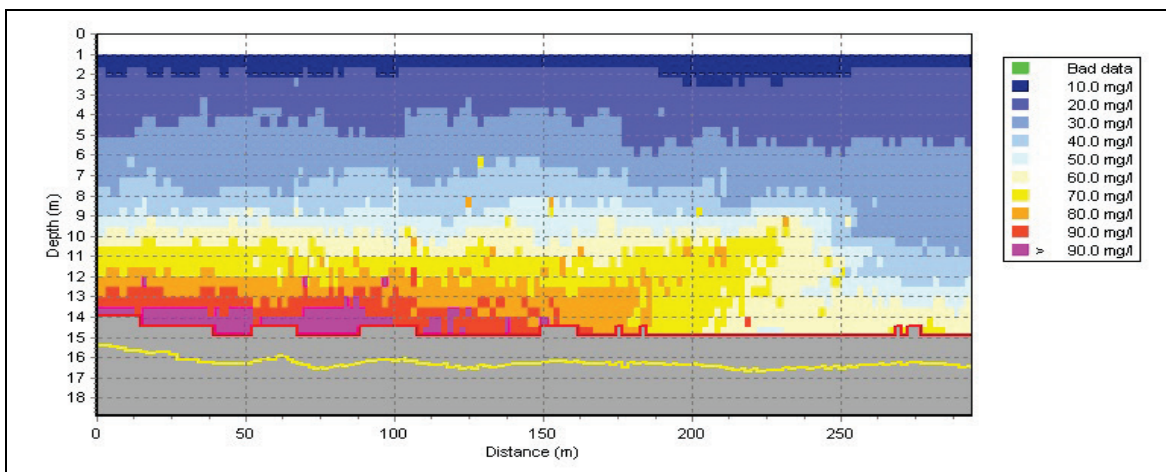


Figure 97. ADCP vertical profile moving eastward (left to right) beginning 593 m south of the bow of the *Cosco Luohabe* after completion of docking maneuvers.

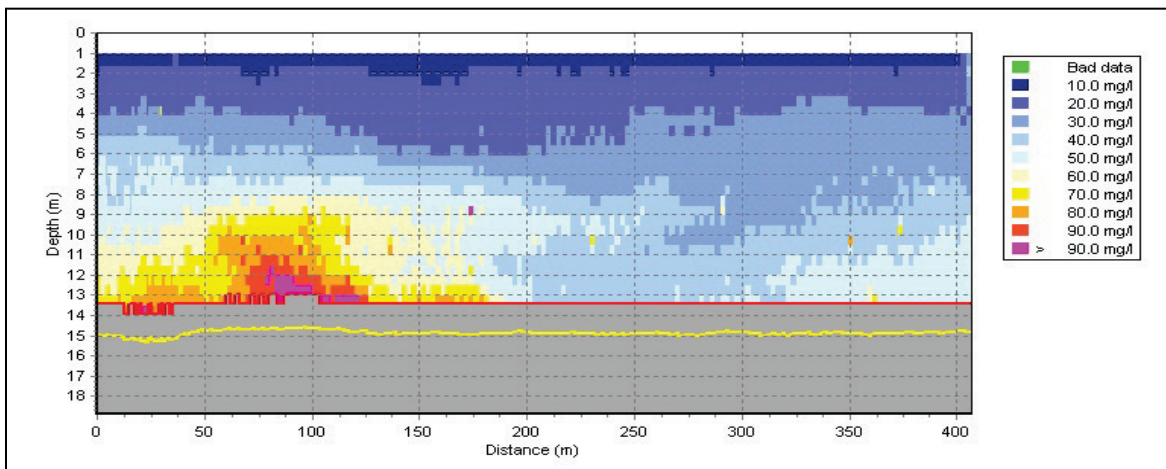
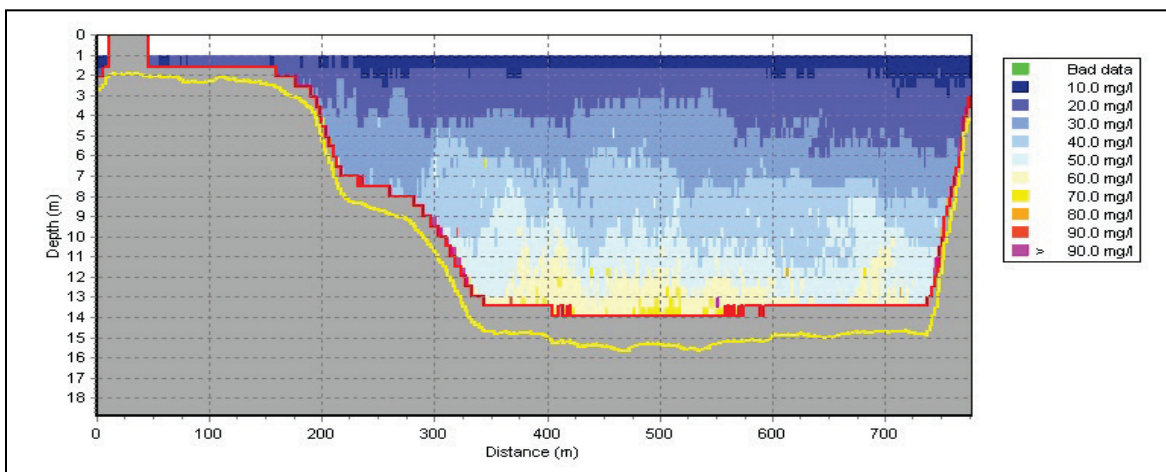


Figure 98. ADCP vertical profile moving eastward (left to right) beginning approximately 1,300 m south of the bow of the *Cosco Luohabe* after completion of docking maneuvers.



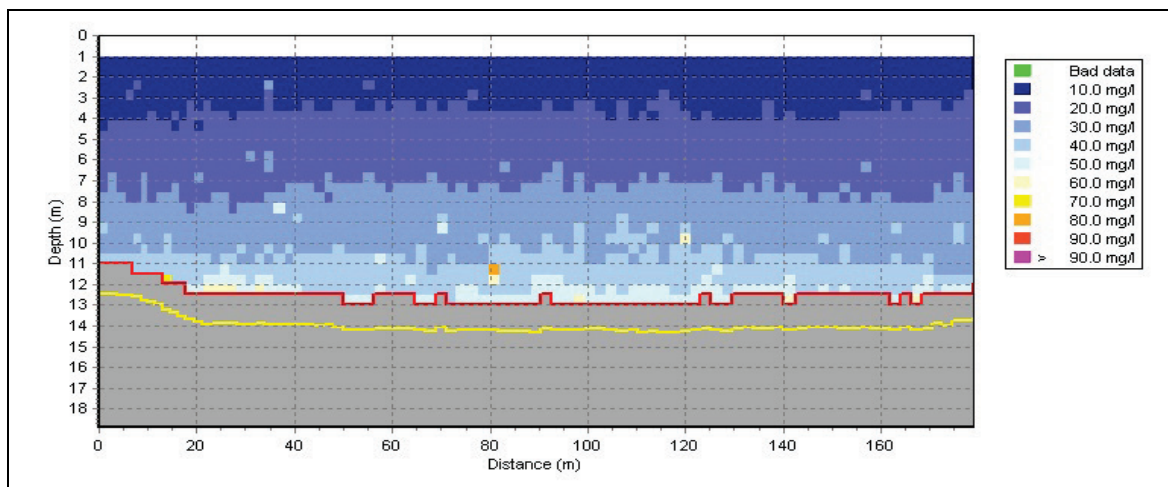
As the plume progressed southward with the ebbing tide, expansion laterally and vertically was apparent. TSS concentrations near the bottom exceeding 90 mg/l occurred at distances over 600 m from the ship, and TSS concentrations 20-30 mg/l above ambient values ranged upward nearly to the surface. Bottom TSS concentrations in the plume track on the final transect remained elevated above ambient conditions at a distance well over 1,000 m from the ship.

On 6 November, a survey was conducted during the departure of the container ship *MSC Fabienne* (Figure 99) during an ebbing tide. The ship was berthed on the north side of the Port Elizabeth Channel until approximately 1420 hr, when two tugs pulled the ship away from the dock. The ship then backed slowly out of the Elizabeth Channel into open bay waters before turning at approximately 1435 hr and proceeding southward toward the Bayonne Bridge at 1440 hr. Three transects were completed at the inner terminus of the Elizabeth Channel prior to passage of the *MSC Fabienne* to capture ambient conditions, as exemplified in Figure 100. Additional transects were then run following behind the ship, first in the Elizabeth Channel, and then moving southward in Newark Bay. The final transect ran from the entrance of the South Elizabeth Channel eastward across the bay until reaching the flats on the Bayonne shore.

Figure 99. Arrival of the container ship *MSC Fabienne* in Newark Bay, New Jersey.



Figure 100. An ADCP vertical profile across the Port Elizabeth Channel prior to the departure of the container ship *MSC Fabienne*.



The series of ADCP transects within the Elizabeth Channel clearly illustrate the significant prop-wash effect as the ship reverses and backs out into Newark Bay. The signature dissipates with increasing distance from the ship (Figures 101 to 104). Once in Newark Bay, the ship began rotating to face southward. Figures 105 and 106 depict the large prop-wash effect as the ship applies power to accomplish the turn. Figures 107 and 108 then illustrate the effect of the ship applying power as it begins its seaward track. The ensuing transects reveal a large, intense plume that dissipates over the span of 40 min as the survey vessel progresses southward behind the departing ship.

Figure 101. Extensive prop-wash signature of the container ship *MSC Fabienne* departing the Port Elizabeth Channel. Transect 534 m from the bow of the ship.

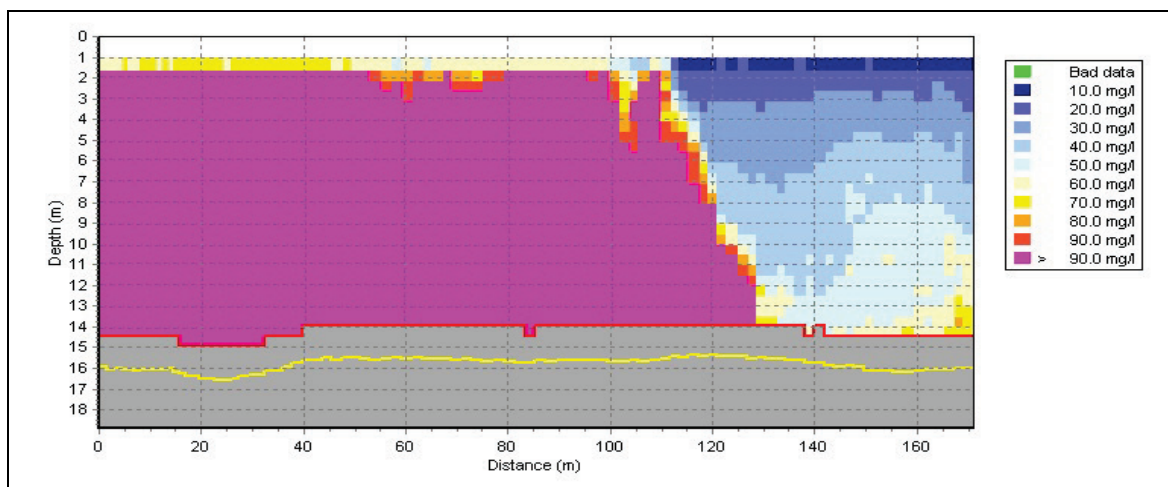


Figure 102. Extensive prop-wash signature of the container ship *MSC Fabienne* departing the Port Elizabeth Channel. Transect 685 m from the bow of the ship.

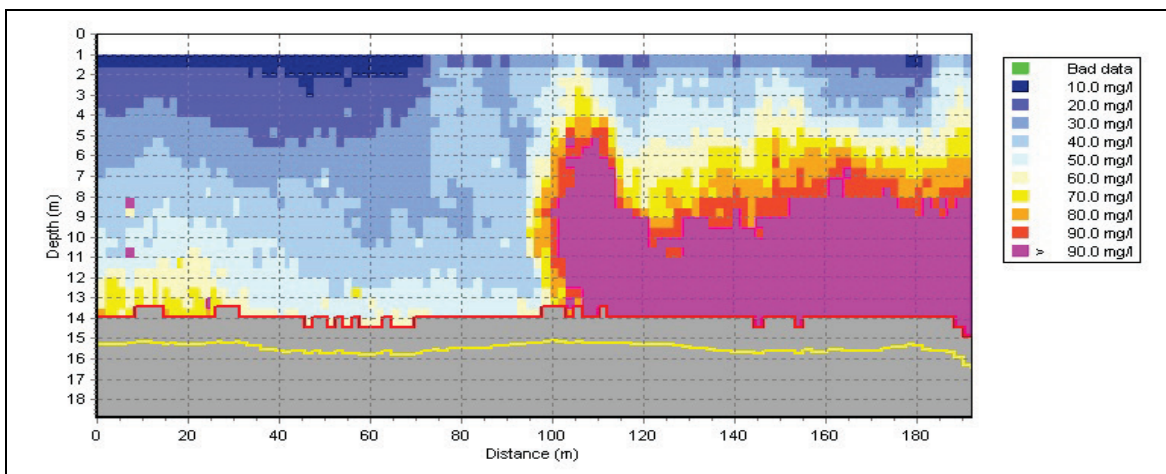


Figure 103. Pop-wash signature of the container ship *MSC Fabienne* departing the Port Elizabeth Channel. Transect 859 m from the bow of the ship.

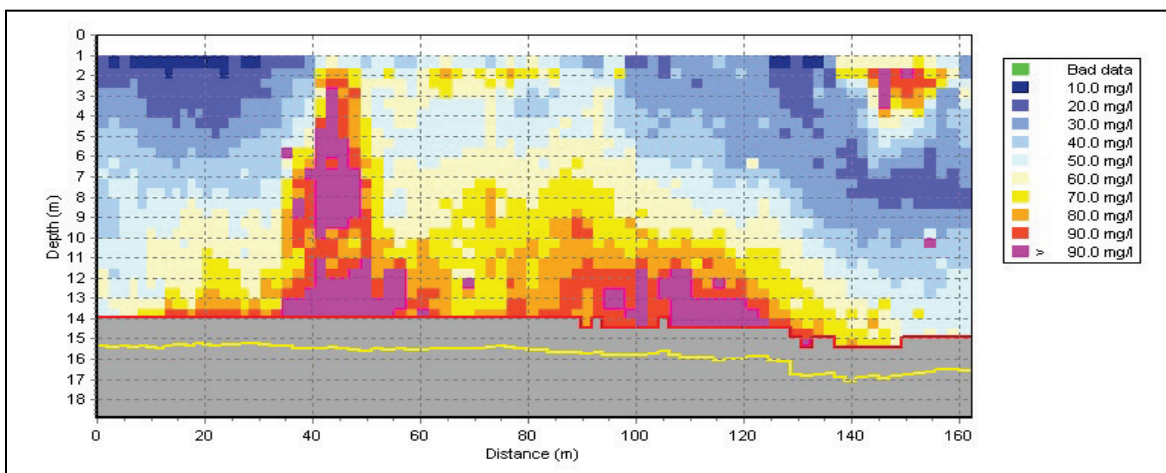


Figure 104. Pop-wash signature of the container ship *MSC Fabienne* departing the Elizabeth Channel. Transect 840 m from the bow of the ship as it backed down the channel.

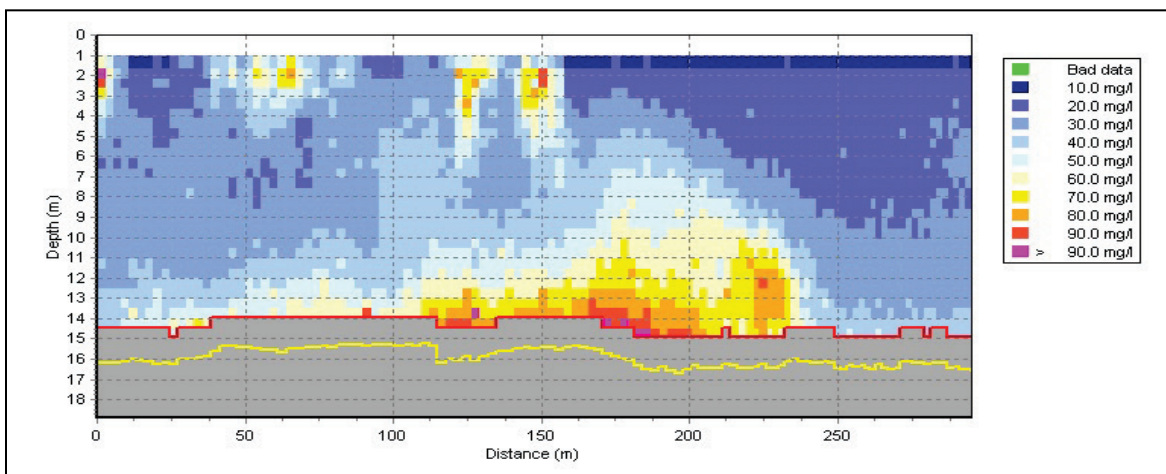


Figure 105. Pop-wash signature of the container ship *MSC Fabienne* while rotating in Newark Bay. The transect runs from east to west (left to right).

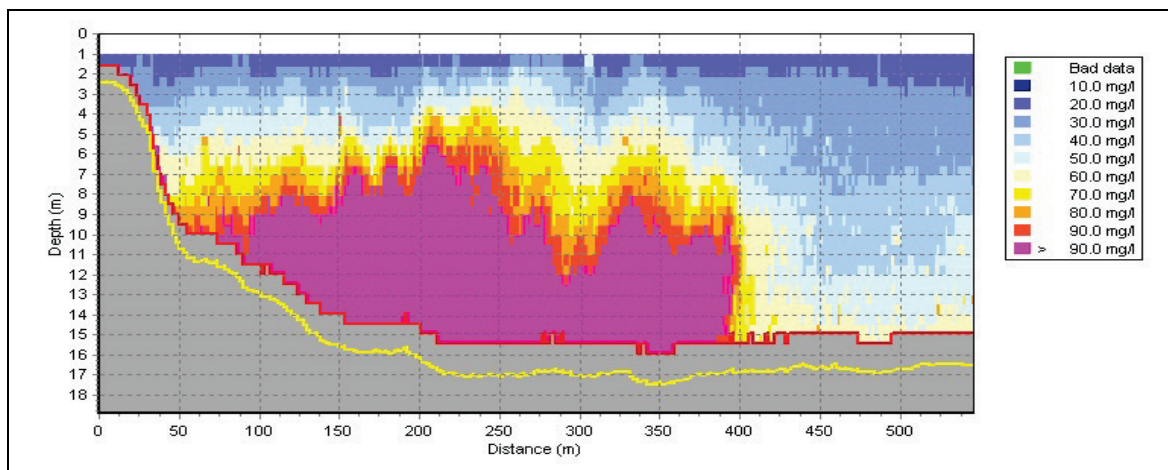


Figure 106. Pop-wash signature of the container ship *MSC Fabienne* while rotating in Newark Bay. The transect runs from east to west (left to right).

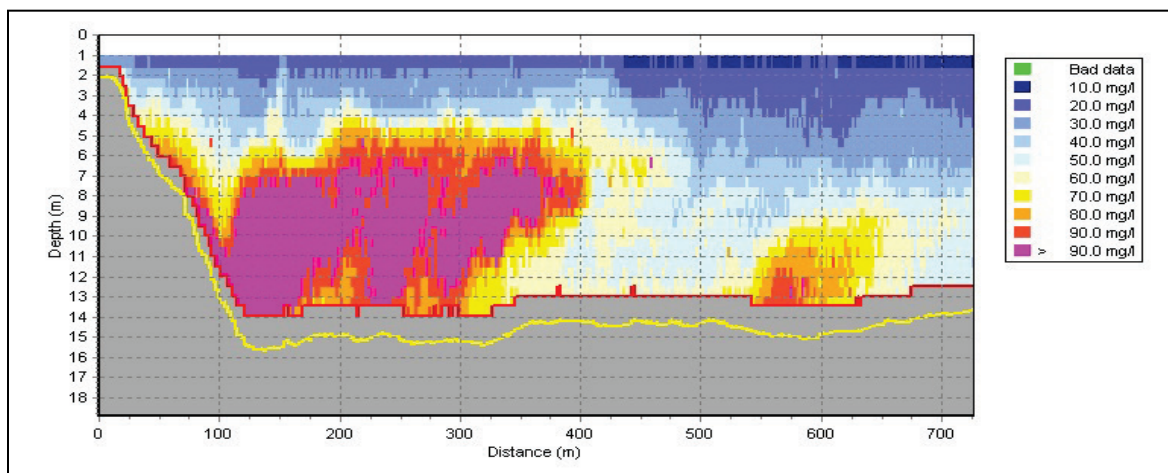


Figure 107. Pop-wash plume signature of the container ship *MSC Fabienne* following departure from Newark Bay. The transect runs from east to west (left to right).

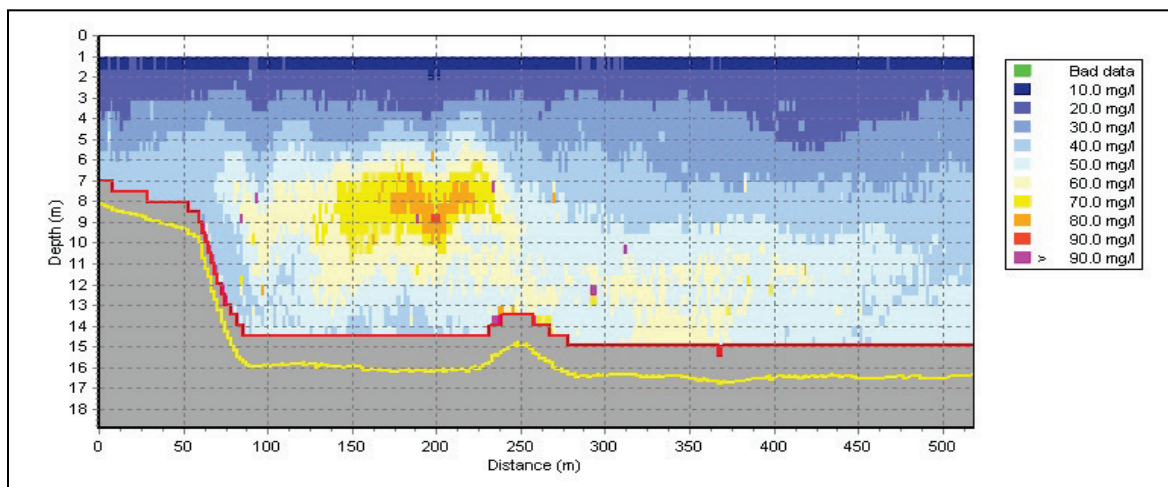
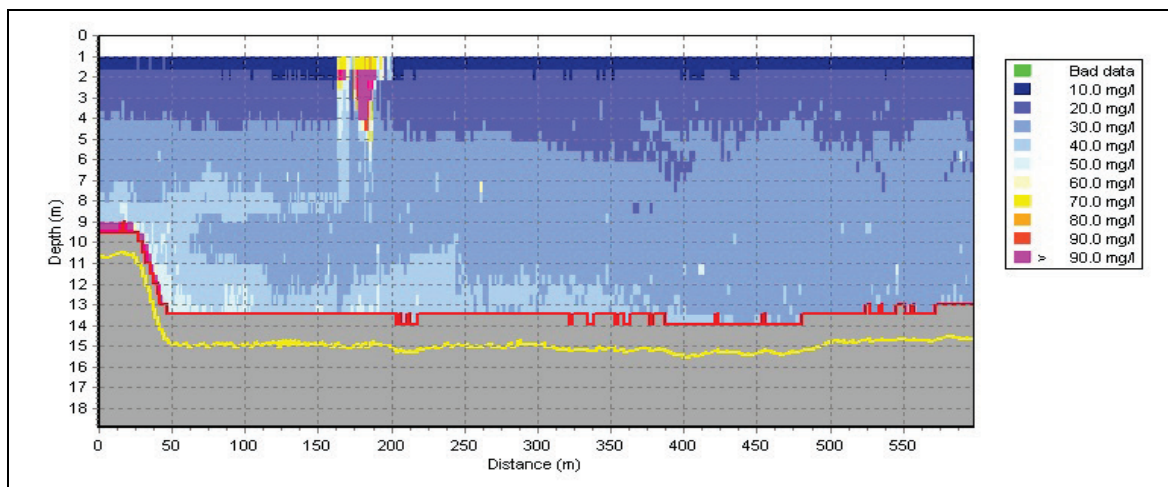


Figure 108. ADCP transect across the lower portion of Newark Bay approximately 30 min after the container ship *MSC Fabienne* departed the bay. The transect runs from east to west (left to right). Prop-wash from a passing tug is shown in the upper water column.



On 8 November, a survey was conducted during the arrival of the bulk carrier *Mandarin Sky* (Figure 109). The *Mandarin Sky* entered Newark Bay at approximately 1200 hr shortly after the arrival of the container ship *Dubai Express* and approximately 30 min before the arrival of the car carrier *DVYI Atlantic*. “Cuing” of the deep draft ships, which spaces the arrivals of multiple ships at roughly 30 min intervals, is a common practice for port facilities in Newark Bay. Thus, on many days the sequential arrivals prevent collection of true ambient data characterizing TSS concentrations. In the case of the *Mandarin Sky*, the ship proceeded to the entrance to the Elizabeth Channel, where assisted by a tug it turned to face into the channel. The ship then moved forward into the Elizabeth Channel and executed a sharp turn to the north into the access channel connecting Port Elizabeth with Port Newark.

The survey to capture the resuspension plume of the *Mandarin Sky* consisted of an initial four east-west parallel transects proceeding northward from a point adjacent to the entrance to the South Elizabeth Channel. Figure 110 shows the surface prop-wash at a distance of 600 m behind the ship and the accompanying bottom plume. Figures 111 and 112 show the dissipation of the plume signature as the ship slowed during its approach to the turning point, and the prominent plume created by the turning maneuver.

Figure 109. Arrival of the bulk carrier *Mandarin Sky* in Newark Bay.



Figure 110. ADCP vertical profile from west to east (left to right), showing prop-wash and plume signatures from passage of the bulk carrier *Mandarin Sky*.

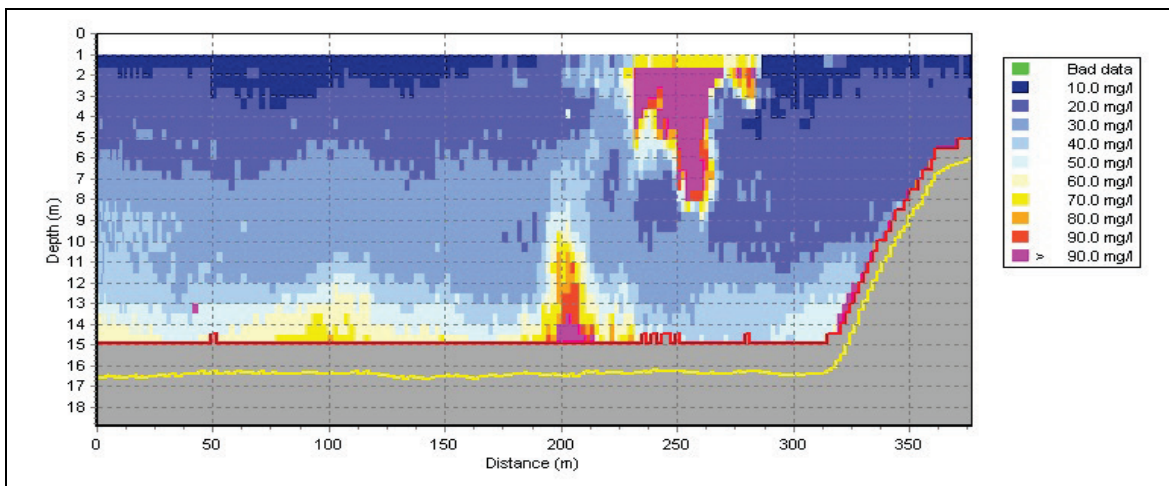


Figure 111. ADCP vertical profile from west to east (left to right), showing plume signature from passage of the bulk carrier *Mandarin Sky*.

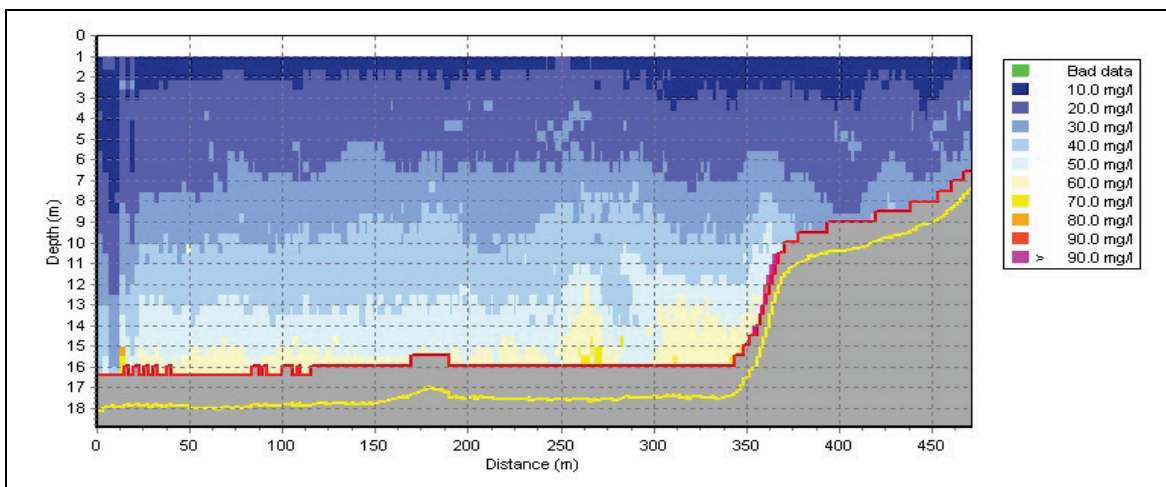
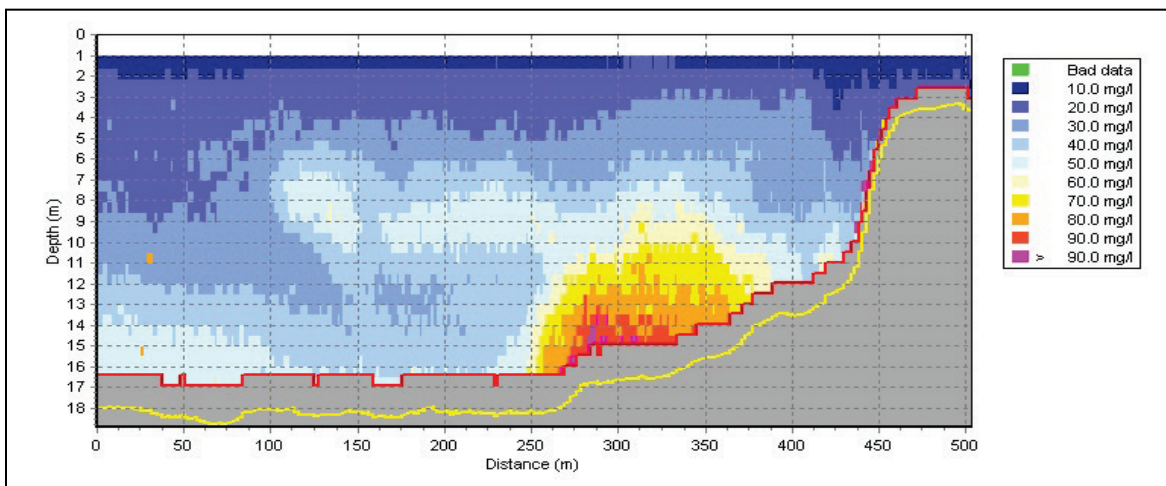


Figure 112. ADCP vertical profile from west to east (left to right), showing plume signature caused by turning maneuvers of the bulk carrier *Mandarin Sky*.



Survey transects then crossed the area behind the *Mandarin Sky* as it entered the Elizabeth Channel. Figures 113 and 114 indicate the spatial scales of the prop-wash and plume effect on the water column through the central portion of the plume and straddling the periphery respectively.

The ensuing transects followed the track of the *Mandarin Sky* into the port access channel. Figure 115 provides an example of the intense bottom plume created immediately astern of the ship's position. A final set of transects progressed into the Port Elizabeth Channel to capture any intrusion of the *Mandarin Sky*'s plume. Figures 115 to 117 show the relatively rapid decay of the plume with increasing distance into the channel.

Figure 113. ADCP vertical profile from east to west (left to right), showing plume signature caused by turning maneuvers of the bulk carrier *Mandarin Sky*.

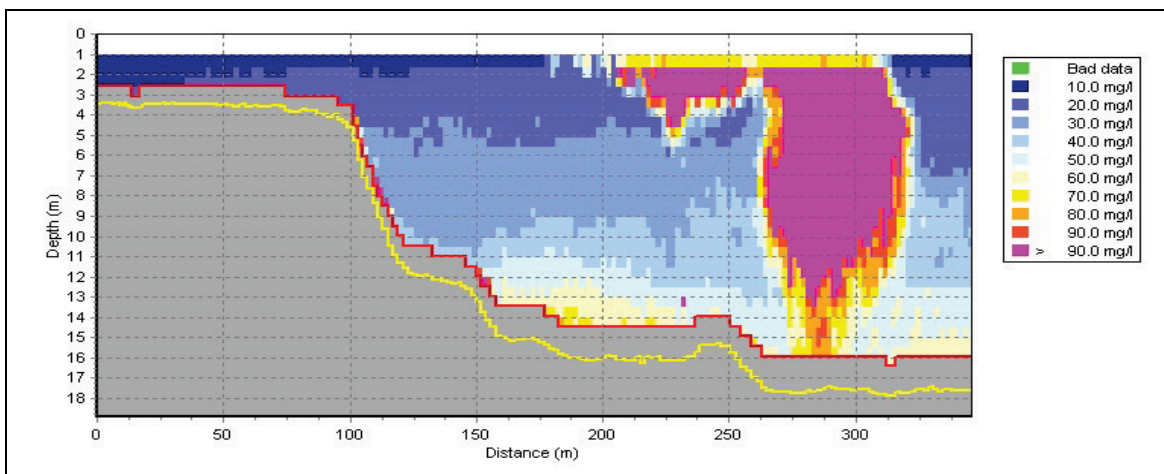


Figure 114. ADCP vertical profile from east to west (left to right), showing plume signature caused by turning maneuvers of the bulk carrier *Mandarin Sky*.

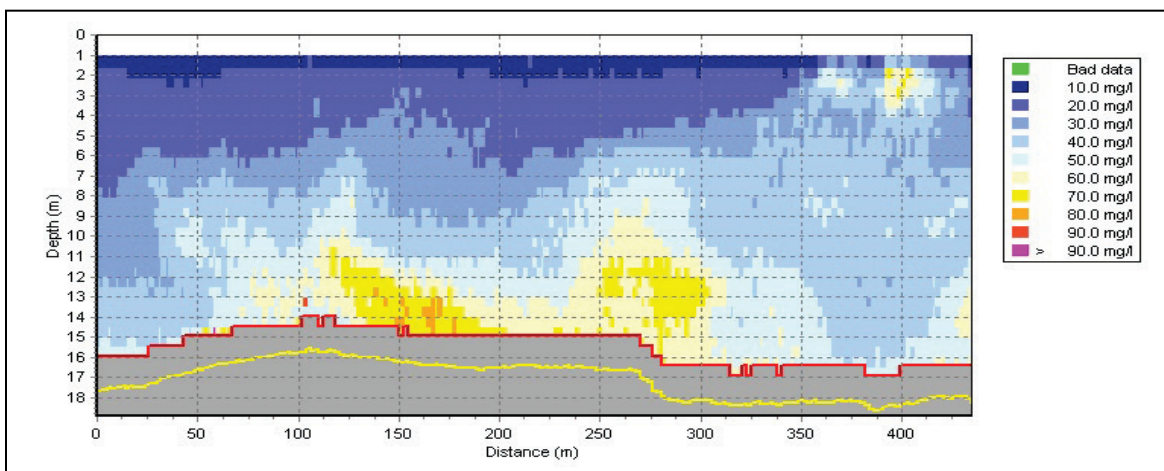


Figure 115. ADCP vertical profile across the entrance to the Elizabeth Channel from south to north (left to right), showing a plume signature astern of the bulk carrier *Mandarin Sky*.

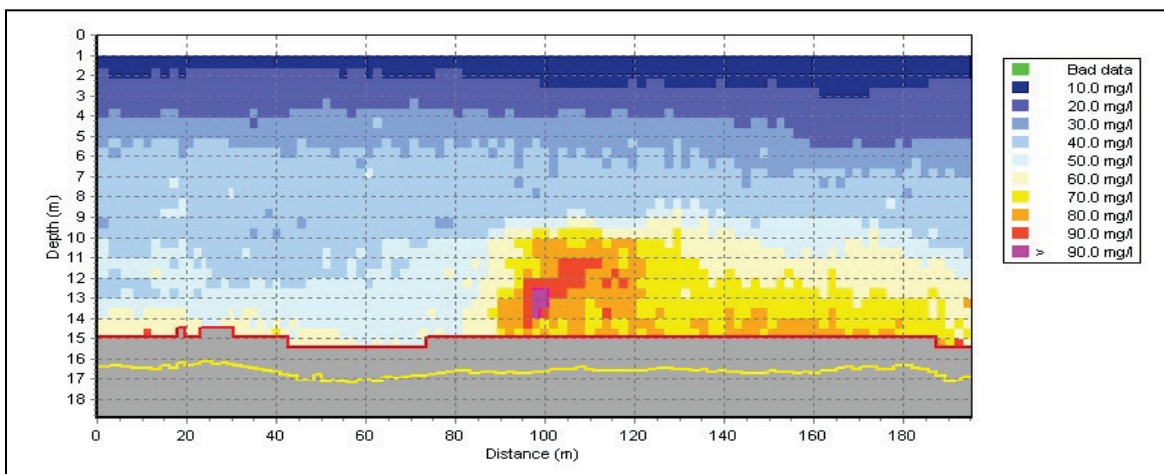


Figure 116. ADCP vertical profile across the Elizabeth Channel from north to south (left to right), showing a plume signature astern of the bulk carrier *Mandarin Sky*.

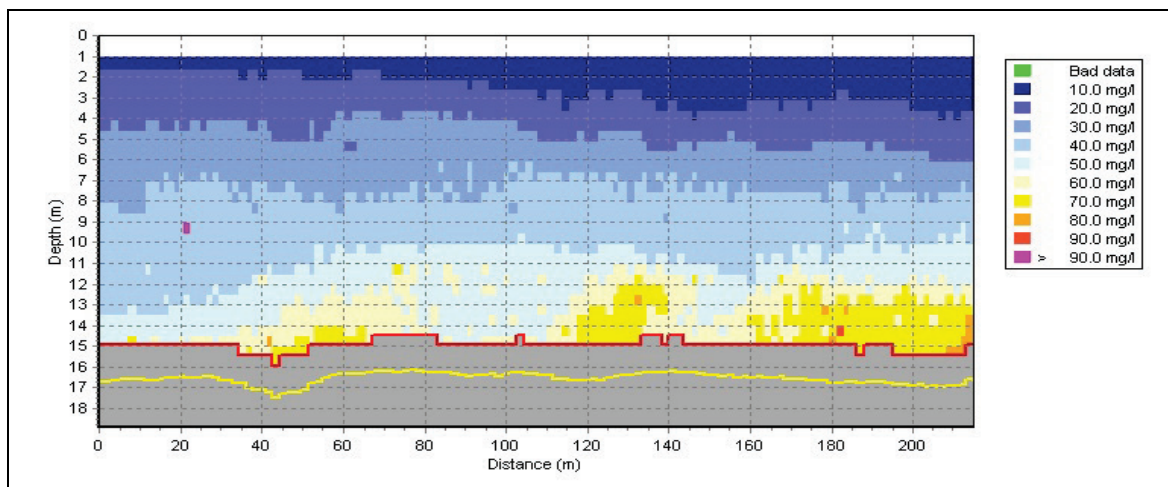
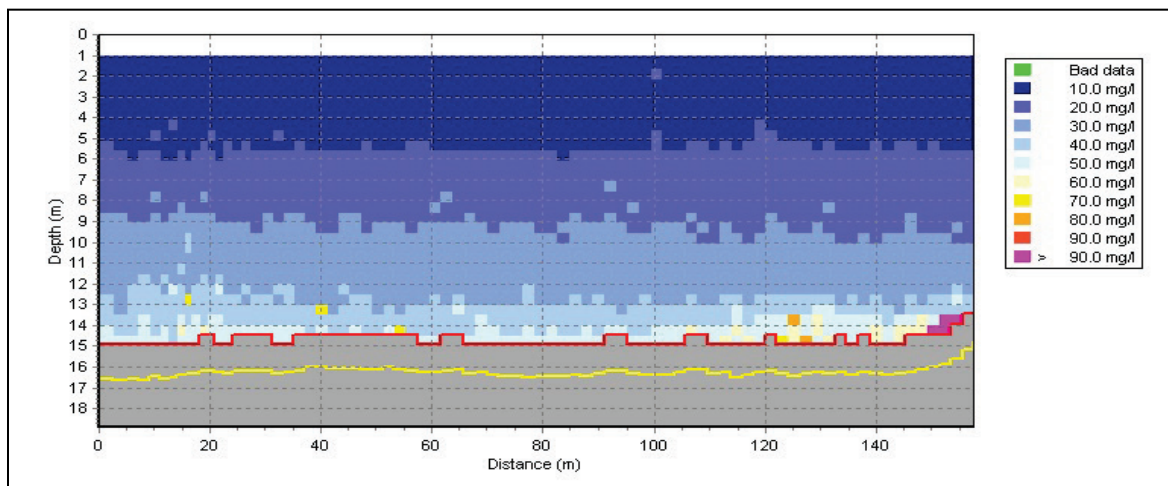


Figure 117. ADCP vertical profile across the Elizabeth Channel from north to south (left to right), showing the absence of a plume signature associated with the bulk carrier *Mandarin Sky*.



On 9 November, two separate surveys were conducted to examine resuspension caused by departure of the container ship *Dubai Express* (Figure 118). In this case, the *Dubai Express* was backed out of the Port Elizabeth Channel by two tugs. Once in open bay waters, the ship rotated and proceeded southward toward the Bayonne Bridge, getting underway at about 1036 hr. The ADCP survey began immediately after passage of the *Dubai Express* and progressed in a northerly direction, following the plume that was carried up-bay by the flooding tide. The survey consisted of fifteen roughly parallel east-west transects. In Figure 119, a bottom to surface prop-wash signature is seen, present at a distance of over 1,300 m from the stern of the departing ship, with smaller prop-wash signatures of the two attending tugs on either side. Progressive plume expansion followed by

decay is seen in the series of vertical profiles presented in Figures 120 to 121. Note that these profiles reflect changes in bathymetry with increasing distance up-bay. Figures 120 through 124 represent cross-sections through deep water (approximately 13 m) up to the confluence with the Elizabeth Channel. Figures 125 and 126 represent transects that crossed the shallower (11 m) channel extending northward to the confluence with the Port Newark Channel, and the remaining figures (Figures 127 and 128) represent transects across the navigation channel further to the north. A continuous plume, largely within the lower half of the water column, was detected along at least two-thirds of the long axis of Newark Bay, with the final transect upon which the plume was detected completed at approximately 70 min following departure of the *Dubai Express*.

Upon completion of the northernmost ADCP transect, the survey vessel reversed course to occupy the same transects while progressing in the down-bay direction. Plume TSS concentrations were generally reduced on all transects, with residual plume signatures primarily near the confluence with the Port Newark Channel (Figure 129, which corresponds to Figure 128 in the previous series). This transect was completed approximately 2 hr following departure of the *Dubai Express*, demonstrating the persistence of plumes in the channel basin.

Figure 118. The container ship *Dubai Express* maneuvering in Newark Bay.



Figure 119. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

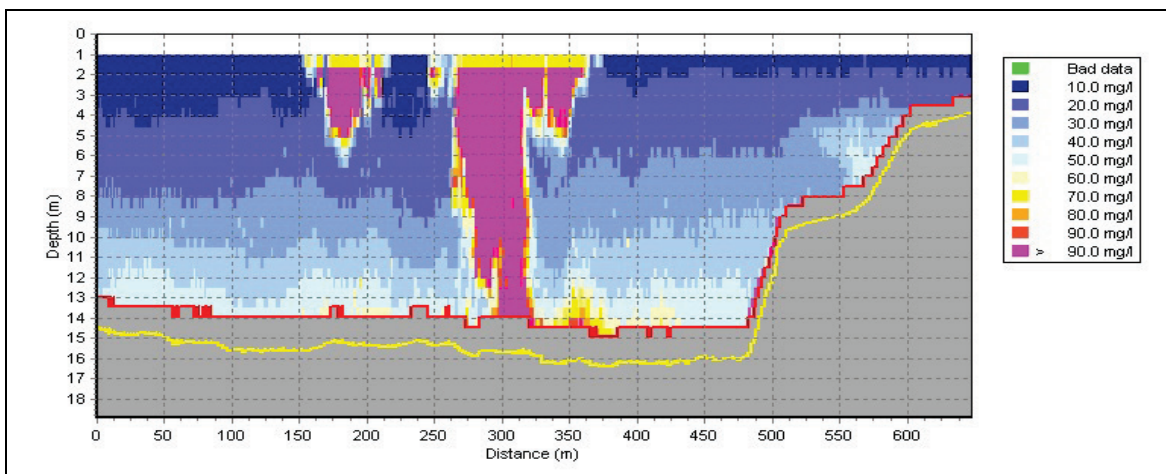


Figure 120. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

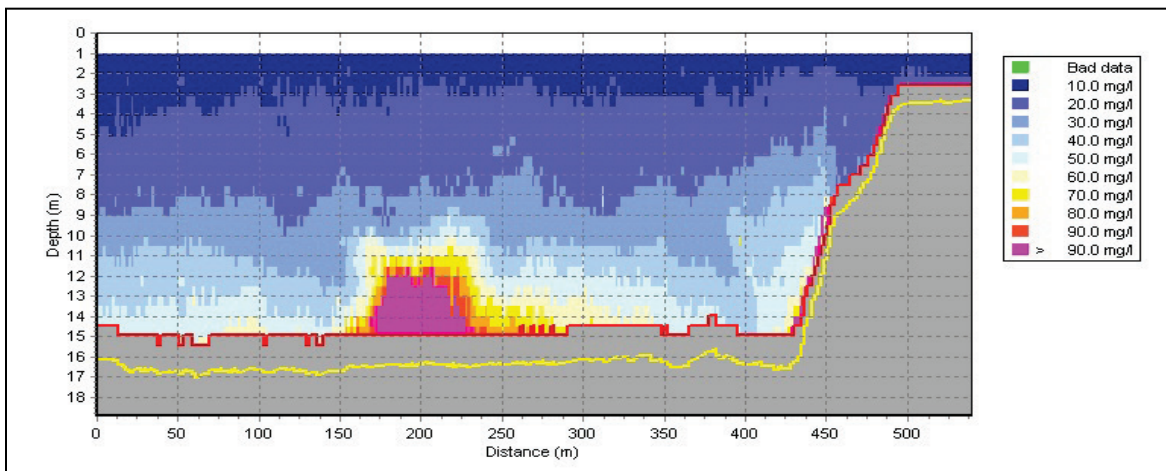


Figure 121. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

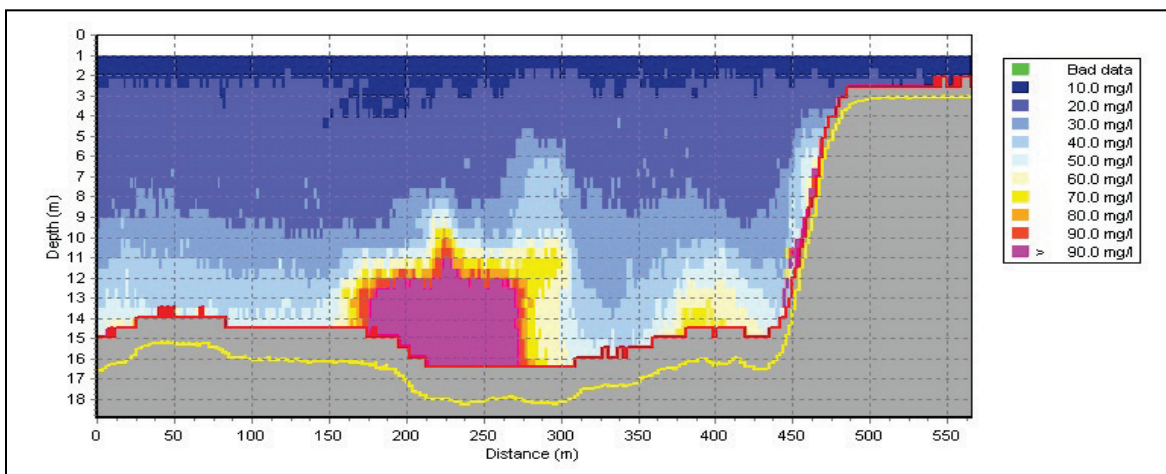


Figure 122. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

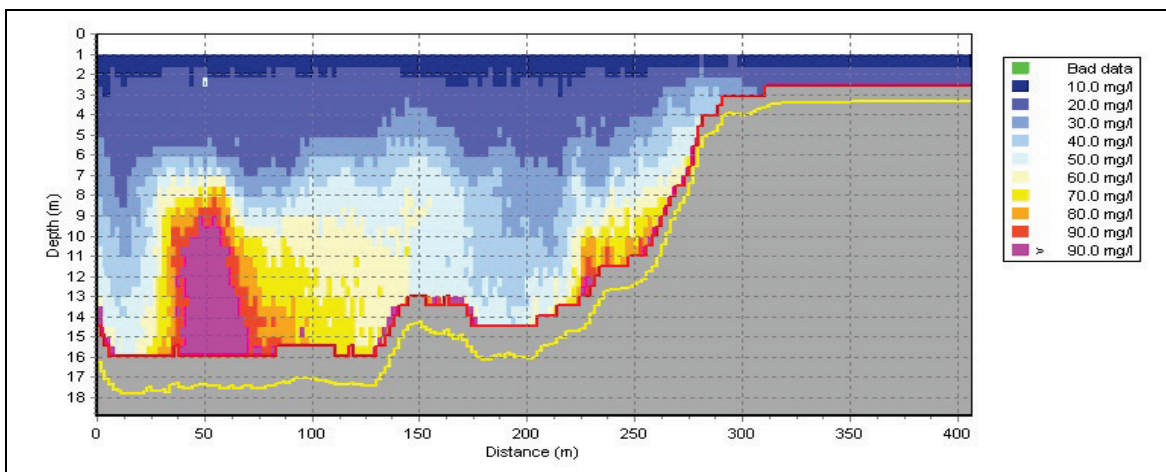


Figure 123. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

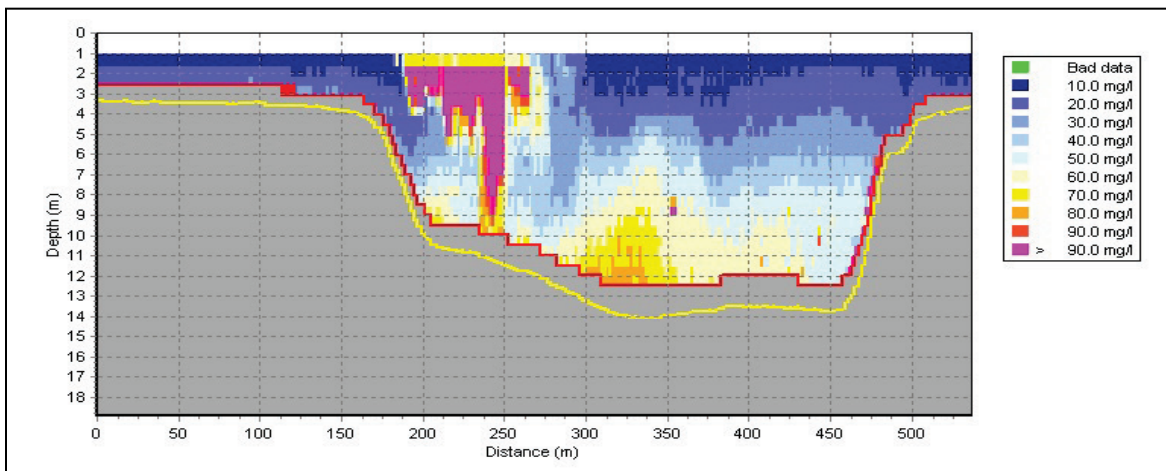


Figure 124. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

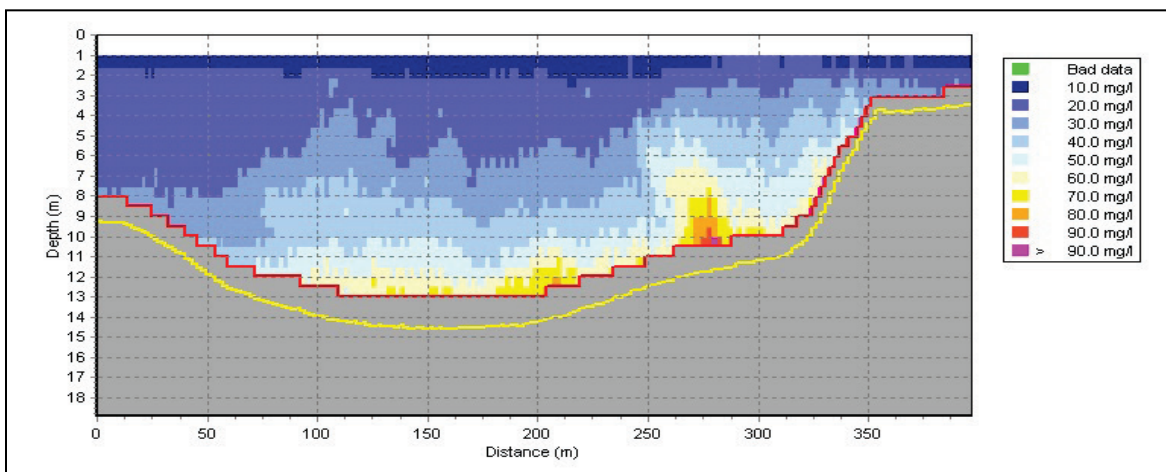


Figure 125. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

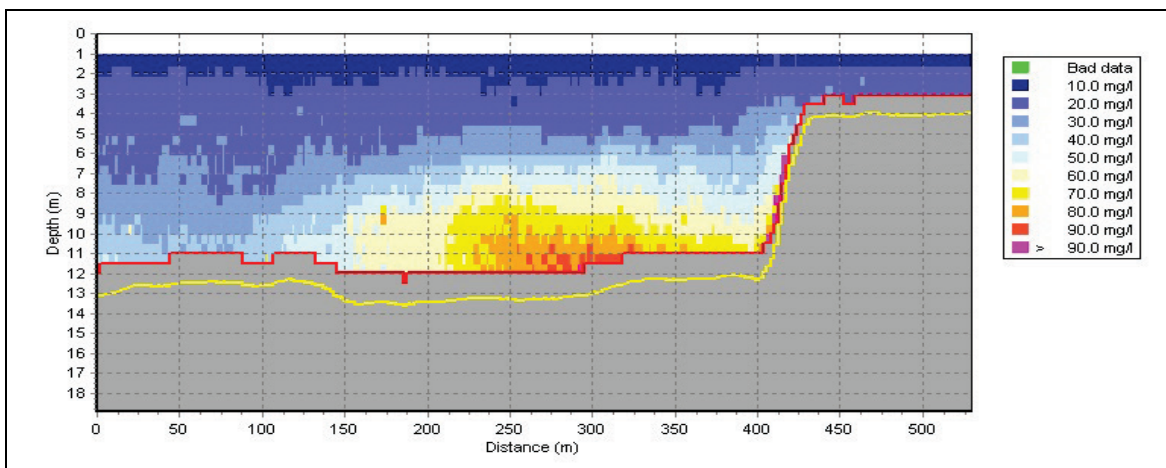


Figure 126. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

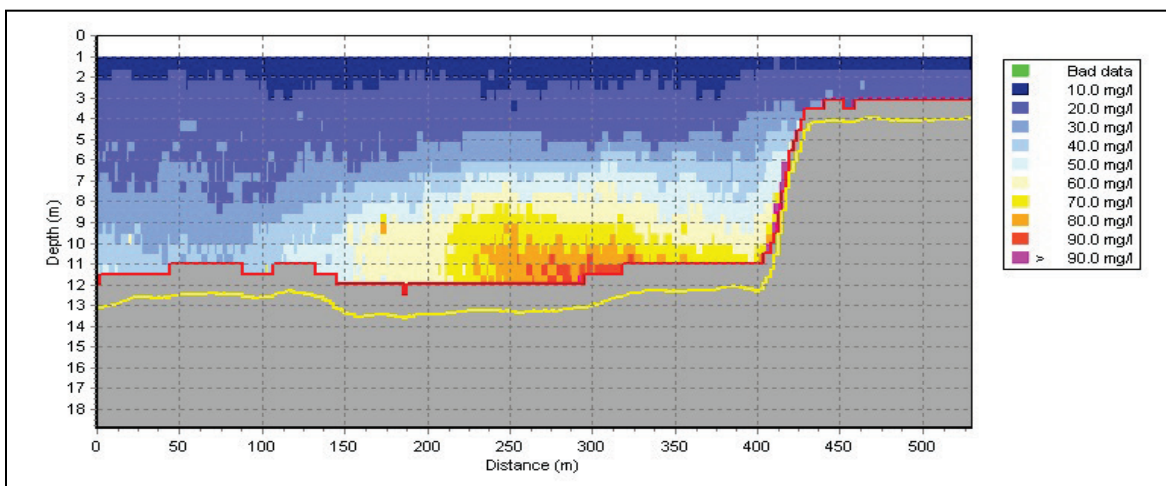


Figure 127. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

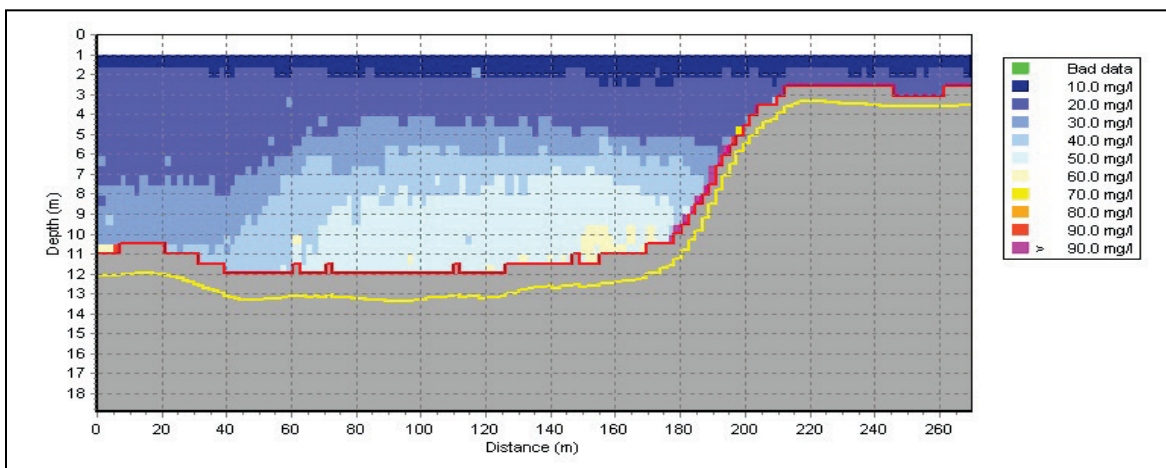


Figure 128. ADCP west to east (left to right) vertical profile of the departure of the container ship *Dubai Express* from Newark Bay.

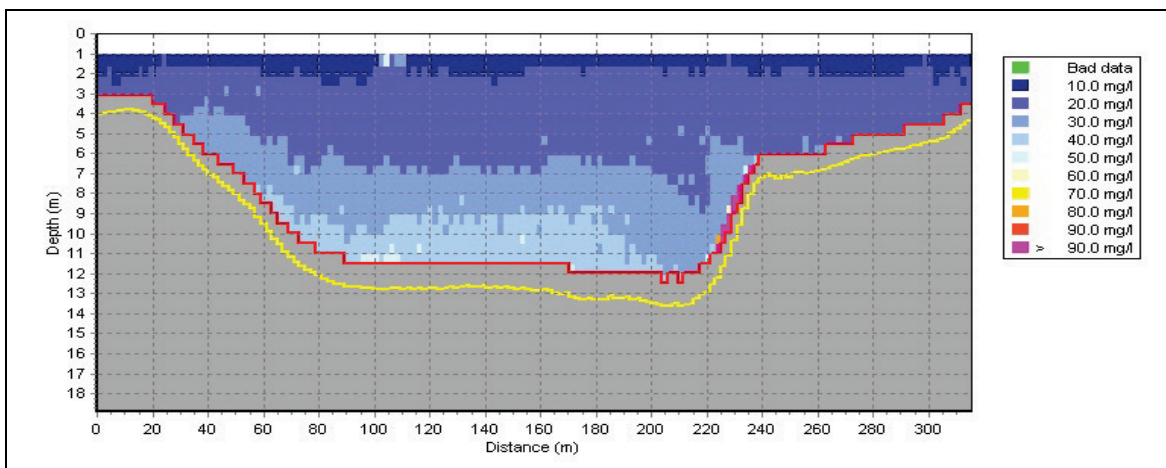


Figure 129. ADCP transect from east to west (left to right) across the navigation main Newark Bay navigation channel immediately north of the confluence, with the Port Newark Channel following departure of the container ship *Dubai Express*.

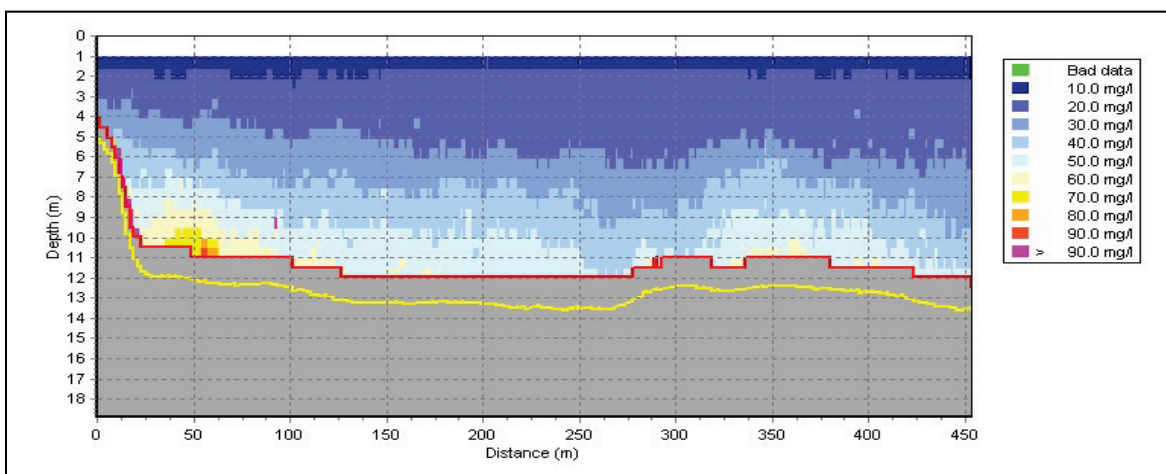


Figure 130. The container ship *MSC Noa* departing Newark Bay.



On 10 November an ADCP survey was conducted during the arrival of the container ship *MSC Noa* (Figure 130). The ship entered Newark Bay at approximately 1115 hr and arrived at the entrance to the Elizabeth Channel at approximately 1130 hr. At that point, the ship was rotated into position to be backed into the Elizabeth Channel stern first. The ADCP survey began as the ship was maneuvered into a berth on the north side of the Elizabeth Channel. Because the tide was flooding, the survey began immediately south of the ship's rotation area and progressed northward. Figure 131 represents a transect running from the entrance to the Elizabeth Channel eastward through the ship rotation area about twenty min after the *MSC Noa* had rotated. A clear separation between the rising prop-wash signature and the suspended sediment plume on the bottom is evident. In sequence, Figures 132 to 134 depict the decay in the suspended sediment plume with increasing distance northward in the main navigation channel.

Figure 131. An ADCP transect through the area in Newark Bay in which the container ship *MSC Noa* had rotated.

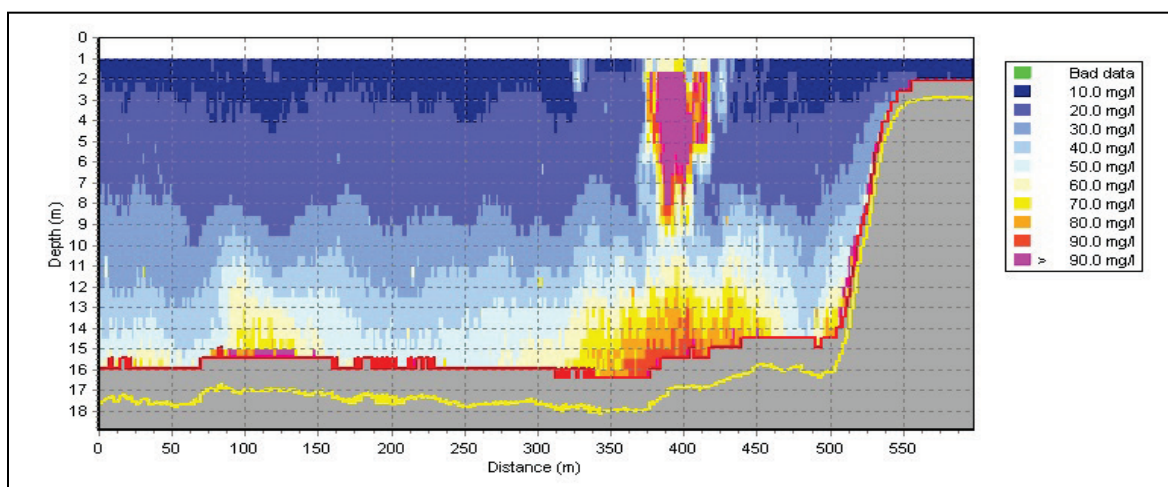


Figure 132. An ADCP transect immediately north of the area in Newark Bay in which the container ship *MSC Noa* had rotated.

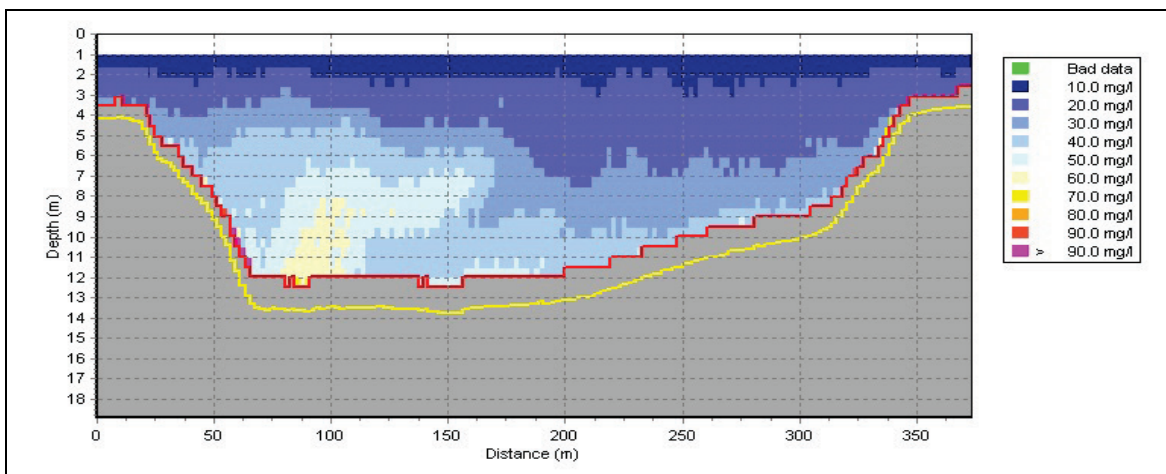


Figure 133. An ADCP transect through the main Newark Bay navigation channel north of the area in Newark Bay in which the container ship *MSC Noa* had rotated.

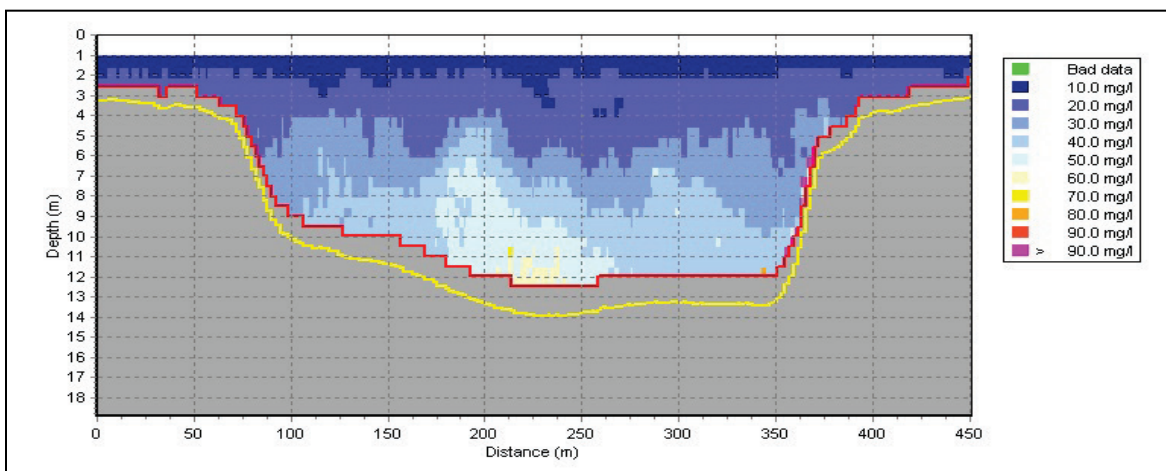
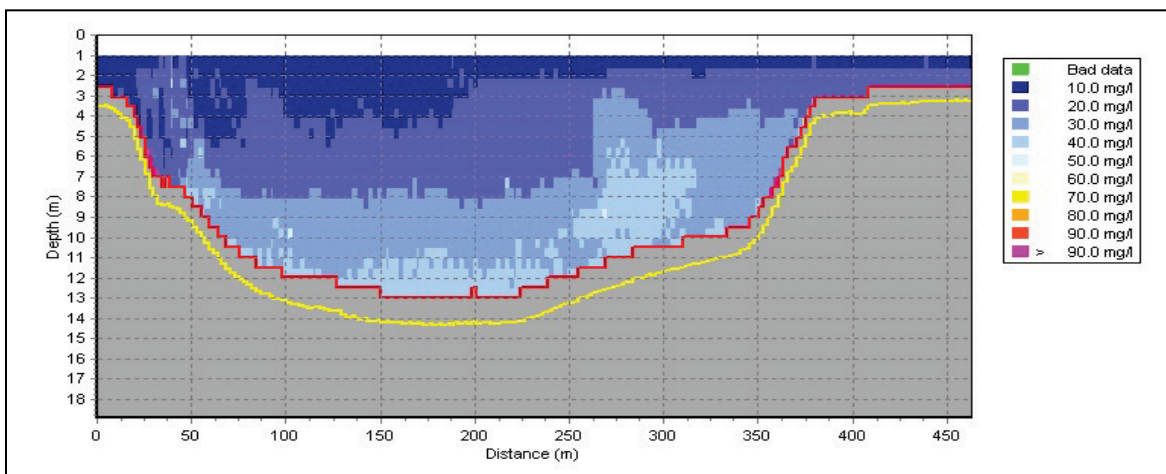


Figure 134. An ADCP transect through the main Newark Bay navigation channel north of the area in Newark Bay in which the container ship *MSC Noa* had rotated.



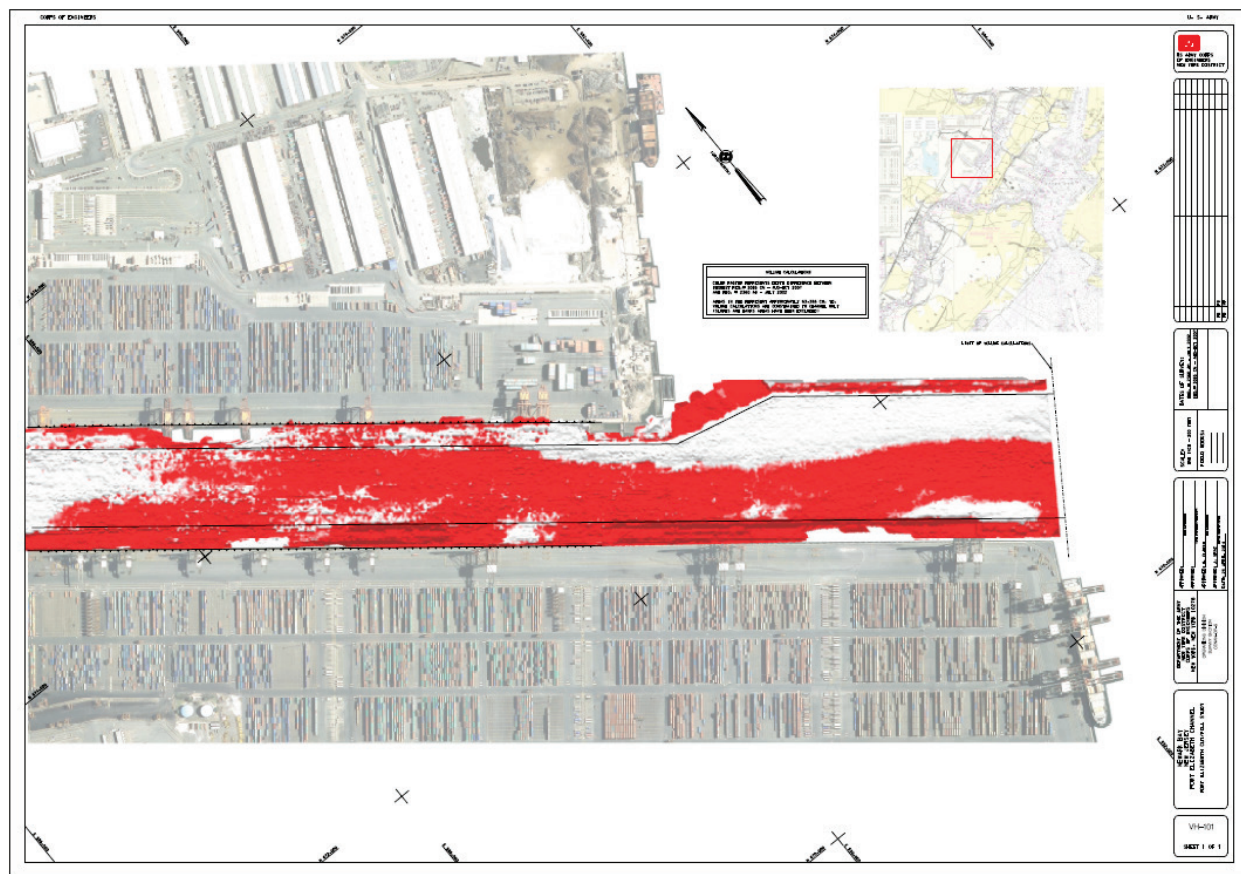
Corroborative Evidence of Ship-Induced Sediment Suspension

During the course of the study, many of the federal navigation channels in the middle to southern portions of Newark Bay underwent successive phases of channel deepening. As part of the Kill Van Kull and Newark Bay Channel Deepening Project, the federal navigation channels from Port Elizabeth Channel through the Kill Van Kull Channel were deepened from a navigable depth of -40 ft mean low water (MLW) to -45 ft MLW in 1999 through 2004, and to -50 ft MLW thereafter. As the underlying substrate within Newark Bay is hard (typically either consolidated Pleistocene red-brown clay, glacial till, sandstone, or shale bedrock), the channel deepening required 2 ft of additional excavation for safety. Advances in the precision and accuracy of multi-beam bathymetric surveying technology combined with the successive deepening of these federal channels provided an opportunity to indirectly measure the magnitude of ship prop-wash sediment suspension of underlying previously undisturbed sedimentary deposits located in the channels.

To estimate the volume of Holocene silt deposits present prior to the second phase of channel deepening (going from 45 ft to 50 ft), pre- and postdeepening bathymetric surveys were compared. This survey difference calculation demonstrated not only substantial sediment accumulation within the channels (as would be expected within deepened channels in an estuary), but also substantial sediment scour in channel areas, with underlying hard sediment substrate (e.g., consolidated Pleistocene red-brown clay).

Figure 135 illustrates (in red shading) areas of the Elizabeth Channel, which experienced measurable erosion of Pleistocene-age sediment from the period when the channel was deepened to at least 47 ft in July 2002 to the period prior to its deepening to at least 52 ft, as measured in August through October of 2007. The volume of sediment scoured in the federal channel during the 62-month span was estimated to be approximately 63,400 cubic yards (CY). The Holocene-age sediment accumulation in the non-shaded areas of the figure was estimated to be approximately 192,000 CY. Assuming that ship prop-wash resuspension dissipated within 1-2 hours following ship passage, the sediment scour due to prop-wash appears to account for approximately one-third of the source of new sediment deposits within the channel itself.

Figure 135. Depiction of changed bathymetry in the Elizabeth Channel following an initial phase of deepening.



Subsequent channel deepening created a second opportunity to estimate the extent of prop-wash scour within the channel. Surveys performed in April 2010 following the second phase of channel deepening to -52 ft, when compared to surveys performed in January 2014, prior to removal of accumulated shoal scour, accounted for an estimated 19,090 CY over a period of 44 months. While this scour volume was less per month than determined from the previous surveys, several significant storms had occurred during that time interval, potentially depositing sediment from natural outside sources and shielding the underlying Pleistocene clays from erosion. An economic downturn contributing to fewer ship passages, and the deepened channel providing greater clearance under the keel of passing vessels may have been additional factors.

4 Discussion

The present study provides substantial evidence that deep-draft vessels represent a significant source of sediment resuspension. Multiple surveys yielded a consistent picture of broad, expansive TSS plumes. Since the source of the plumes is moving rather than stationary, the plumes tend to be diffuse. That is, the TSS concentration gradients within the plumes in deep-draft vessel wakes do not appear to contain pockets of very high concentration. The mass of sediment resuspended is injected into the water column with sufficient propeller-induced velocity to ensure dispersion throughout the water column. In addition, prevailing tidal circulation affected the transport of plumes either in an up- or down-bay direction. Many examples of prop-wash effects encompassing the entire water column were observed in the surveys. The areal extents of the plumes were so large that even mobile ADCP surveys could only capture partial characterizations of the plumes, rather than true maps of plume boundaries. However, collectively, the surveys develop a relatively detailed depiction of ship-induced sediment resuspension in Newark Bay. In addition to the substantial evidence of the large spatial scales associated with deep-draft vessels, the durations of these plumes were notable. Given the frequent practice of having multiple vessels enter the ports in cues separated by approximately 30 min, many plumes would not completely dissipate to ambient conditions before the passage of another vessel. Clearly, for extended periods during multiple vessel arrivals and departures, TSS concentrations remain elevated, especially in the lower portion of the water column. This is consistent with characterizations of plumes of all sources wherein concentrations decay rapidly in the upper water column.

Variation in the extent of resuspension was observed among the surveyed vessel passages. Although there is a great deal of tug, barge, and miscellaneous categories of shallow-draft vessel activity in Newark Bay, little evidence was seen that these vessels produced a prop-wash effect that reached the bottom while they were underway. Passage of several tugs in tandem with barges, while disturbing the upper portion of the water column, did not appear to measurably affect the bottom. However, tugs assisting the container ships in rotating and docking maneuvers appeared to contribute to sediment resuspension. Differences in draft that equate to clearance of the keel of a given vessel above the bottom also may contribute

to observed differences in plumes. For example, passage of an outgoing car carrier did not create a prominent plume. Invariably, acoustic signatures clearly depicted large areas of bottom and water column disturbance for maneuvering container ships, with evidence of significant movement and resettlement of sediment. Independently, Murphy et al. (2011a, b) reported characterizations of Newark Bay sediment regimes based on side scan sonar mapping techniques. Figure 136 clearly illustrates the results of prop-wash scour where the container ships maneuver at the confluence of the Elizabeth Channel with Newark Bay. High-reflectance, brighter-colored sediments indicate the presence of hard, consolidated sediments; whereas darker, low-reflectance sediments indicate softer substrates. The continual scouring of sediments from the turning maneuvers of deep-draft vessels prevents accumulation of soft, newly deposited sediment. The fans of consolidated sediment in the opposing directions of prop-wash forces cover a substantial surface area of bay bottoms.

Figure 136. Side-scan sonar mosaic of lower Newark Bay.



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14. ABSTRACT A frequently cited concern for potential detrimental impacts to aquatic organisms associated with dredging projects is sediment resuspension resulting from the excavation process, overflow, or open-water placement. However, very few attempts have been made to place dredging-induced resuspension into perspective with other natural (e.g., tidal flows, high riverine discharges, storm wind and wave forces) or anthropogenic (e.g., commercial or recreational vessel traffic passage and maneuvering) sources of resuspension. The present study examines suspended sediment plumes created by various types of vessels within Newark Bay, New Jersey. Spatial scales, total suspended solids (TSS) concentration gradients, and dispersion patterns were measured by a combination of acoustic Doppler current profiler (ADCP) surveys and collection of water samples for gravimetric analysis. Plumes varied substantially among vessel type and movement patterns. Often very large plumes, initially extending from the surface to the bottom, were associated with turning maneuvers of deep draft vessels. Plumes rapidly dissipated in the upper portion of the water column, but persisted at depth for relatively long periods. TSS concentrations above 90 mg/l occurred over broad areas following vessel maneuvers. Ambient TSS concentrations ranged from 10 mg/l (surface) to 60 mg/l (just above the bottom). Bottom plumes remained detectable against ambient throughout the time intervals between successive arrivals and departures, persisting for at least 50 minutes where tidal currents could disperse plumes. Residual plumes (maximum 40 mg/l) in the lower 2 m of the water column were detectable at the point of deep draft vessel passage up to 65 minutes.					
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